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ENGINEERING:

An Illustrated Weekly Journal.

EDITED BY WILLIAM H. MAW AND B. ALFRED RAWORTH.

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VOL. CVII.—No. 2780.] *LONDON: FRIDAY, APRIL 11, 1919.* [*Registered at the General Post Office as a Newspaper.*] [PRICE...9d. BY INLAND POST ... 11d.

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See half-page Advertisement page 101, March 21.

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HERBERT REED,
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20th March, 1919. T 723

University of Liverpool, SESSION 1918-19.

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Pontefract.
8th April, 1919. U 71

G. R.

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April 7th, 1919.

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A. C. BOYDE,
Director of Education and Secretary.
Education Office,
North Lodge, Darlington.
April, 1919. U 64

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FACULTY OF SCIENCE.

PROFESSORSHIP OF ELECTRICAL ENGINEERING.

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The stipend offered is £800 a year.
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Education Offices,
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25th March, 1919 T 737

SIR WILLIAM CROOKES, O.M., F.R.S.

THE veteran scientist, Sir William Crookes, passed away on Friday, April 4, in his eighty-seventh year. Few men of science could look back upon so long a span of equally successful and so widely-appreciated activity. For nearly six decades "his unsurpassed experimental skill and the instinct of selecting his subject enabled him to have the first word on almost as varied a range of subjects as any physicist of his country in the past century. And the first word counts for a great deal in experimental research." We quote—though not literally—from the words by which Sir J. J. Thomson, the successor of Sir William Crookes in the presidency of the Royal Society, referred last Saturday to the great loss science had sustained. Sir J. J. Thomson spoke in the Royal Institution, which Crookes had so often delighted, and before opening his lecture on "The Problems of Spectroscopy, Radiation and Atomic Structure," in the elucidation of which the discoverer of thallium and of the radiometer, "the romance of science," had taken so eminent a share.

Sir William Crookes started his scientific life as a chemist, and owes his fame chiefly to researches on the border land between physics and chemistry. Born on June 17, 1832, in London, he joined August Wilhelm Hofmann's College of Chemistry in Oxford-street, London, in 1848. He gained the Ashburton Scholarship, but he did not enjoy any University training, and the degrees of D.Sc. and LL.D., which the Universities of Birmingham, Dublin, Oxford, Cape Town, Sheffield, Cambridge and Durham conferred upon him after 1900, were honorary degrees. During the years 1850 to 1854 he was one of Hofmann's assistants, like Sir William Perkin. His professor title, by which he was generally addressed before he became Sir William, dates from 1855, when he lectured on chemistry at the Training College in Chester. He came there from the Radcliffe Observatory at Oxford, the meteorological department of which he had superintended in 1854. When later he went to Oran, in Algiers, to watch the solar eclipse of 1871, it was chiefly spectroscopical observations that occupied him. In 1859 he settled in London and founded the *Chemical News*, which he himself edited until 1906. Since 1880 almost all his work was done in his private laboratory in Kensington Park Gardens.

In 1850 Hofman placed at his disposal 10 lbs. of seleniferous mud deposit from the sulphuric acid works at Tilkerode, in the Harz Mountains. The presence of tellurium was suspected, the third element of the sulphur-selenium group which Klaproth had isolated in 1798. Crookes did not find tellurium. During the purification of the selenium, and in his study of the selenocyanides, Crookes observed a bright green line in the spectra of his compounds, however, which is still most useful in spectroscopic researches. He finally traced this line, in 1861, to a new metal, thallium; thallium means a green branch. The discovery was made by the aid of spectroscopy, which the combined researches of Kirchhoff, on radiation and absorption (1859), and of Bunsen, on the chemistry of the many complex compounds which were then examined in flames, had raised to the rank of a wonderful analytical method and an exact science.

Photograph by Elliott and Fry.

THE LATE SIR WILLIAM CROOKES, O.M., F.R.S.

The new metal of Crookes' was one of the scientific features of the Hyde Park Exhibition of 1862. The discovery was confirmed in the same year by Lamy, and Crookes and Lamy independently studied the new element. Crookes' determination of the atomic weight of thallium, which resulted in the value Tc = 203·642, is regarded as the best extant. That this value has been changed into 204·0 does not impair the excellence of his investigation, as the change was caused by the re-determination of other constants. Scientifically the discovery was then of high interest; for thallium would not fit at all into the electrochemical series of Berzelius. Here was a metal resembling lead in its general appearance and density, 11·9, yet more silvery white and as soft almost as sodium, to which it seemed closely related in its hydroxide and carbonate, whilst forming compounds with chlorine and iodine after the fashion of gold and mercury, which it follows in the sequence of atomic weight (gold 197, mercury 200·6, thallium 204, lead 207·2). Physiologically thallium proved a poison partaking of the properties of mercury on the one hand, and of potassium on the other. Thus it connected two groups of metals so far separated by a wide gap.

It was during the exceedingly delicate weighings required in these researches that Crookes was puzzled by the apparently capricious behaviour of his balance in a partial vacuum. The student of chemistry soon learns that substances must not be weighed in hot crucibles, because they are then buoyed up by the convection currents in the air. Crookes' anomalies did not cease when he conducted his weighing operation in a relatively high vacuum, and he presented quite a number of papers to the Royal Society in the period 1873 to 1879 on the repulsion resulting from radiation. In 1875 he announced his discovery of the "light mill," or radiometer, in which, he thought, he converted light directly into motion. His lecture on radiant matter to the British Association meeting, held at Sheffield in 1879, made his name universally known and far more popular than that of the great man who had co-operated with him, Sir George G. Stokes. The vacuum bulbs which, in their modifications, had been successively known as Plücker (1859), Hittorf (1869), and Goldstein (1879) tubes, were thenceforth called Crookes' tubes. The tubes were made by Crookes' assistant, the late Charles Henry Gimmingham, whose wonderful skill as glass blower has contributed so much in helping us to the incandescent lamp. When Gimmingham left Crookes in 1881 to join the Swan Electric Light Company — consumption carried him off soon afterwards—Crookes found another very able assistant in Mr. J. H. Gardiner, who collaborated with him till the end.

Backed up by the British scientists, but opposed for a long time by the Continental school, Crookes maintained that we had in kathode rays to deal with "radiant matter," matter in a fourth state —neither liquid, solid nor gaseous. "We seemed at length to have within our grasp and obedient to our control the little indivisible particles which are supposed to constitute the physical basis of the Universe. In some of its properties radiant matter is as material as this table, in other properties it almost assumes the character of radiant energy.

We have actually touched the border land where matter and force seem to merge into one another; the shadowy realm between the known and the unknown, which for me had always a peculiar temptation. I venture to think that the greatest scientific problems of the future will find their solution in this border land and even beyond."

How fully these predictions have been realised, though not exactly in the expected sense, is too well known to need repetition. In the subsequent elucidation of kathode rays, electrons and radio-active phenomena Crookes himself is identified with the chemical separation of uranium-X from uranium (1900), with the stratification of the electric discharge through gases (1902), and with the discovery of the spinthariscope (1903), the simple little apparatus by the aid of which we see the alpha particles shot out by radium call forth scintillations in the target of zinc sulphide which they strike, the most direct demonstration of radio-activity and of the discontinuity of the structure of matter.

The passage we quoted above from Crookes' lecture is characteristic also for its reference to the shadowy realm between the known and the unknown. It is generally known how much the "beyond" tempted Crookes, and that he believed himself to have established, with the aid of a spiritualistic medium, certain manifestations incompatible with the general laws of gravitation. He described these experiments in his book on "Researches on the Phenomena of Spiritualism" 1874). Later on he refrained from giving publicity o these views. He served, however, as President of the Society of Psychical Research in 1896 to 1899, and when he addressed the British Association as President at Bristol in 1898, and touched in his concluding remarks upon a subject—"to me the weightiest and furthest reaching of all"—viz.: his interest in psychic researches, he said: "I have nothing to retract. I adhere to my already-published statements. Indeed, I might add much thereto. I regret only a certain crudity in those early expositions which, no doubt, justly militated against their acceptance in the scientific world."

His researches on the viscosity of gases at high exhaustion was another outcome of his investigation of radiant matter. Maxwell had theoretically and experimentally demonstrated that within limits the viscosity of a gas should be independent of its density. Kundt and Warburg had given additional verifications, and Crookes himself succeeded in furnishing a further experimental proof by watching the subsidence of a delicately-suspended lamina oscillating in a gas. At the highest exhaustion Maxwell's law broke down, as Maxwell had foreseen; Stokes again supplemented the theory. When the density was reduced to 1/1000 of that of the atmosphere, the apparent attraction by heat changed into repulsion, which diminished more and more with complete rarefaction. When Crookes first recognised this fact he thought he had experimentally established the radiation pressure of light, whose complete theory had just been given by Maxwell and by Bartoli. But Zoellner demonstrated that the Crookes effect was about 100,000 times too large, and it was, as is now well known, not until 1900 and 1901 that the radiation pressure was experimentally verified by Lebedev and by Nichols and Hull.

In highly rarefied air Crookes maintained a gold leaf electroscope charged for months. In 1881 Crookes published his paper on "Radiant Matter Spectroscopy," based upon the familiar fact that kathode rays render many substances phosphorescent. Some of the rare earths which he isolated by very laboricus, systematic researches from gadolinite gave a continuous phosphorescence spectrum. Notable among them was scandium, so rare on our earth, so common apparently in the stars. His proclamation of a new element, victorium (to which he assigned the atomic weight of 100·17), of ionium and another element, rested, merely on spectroscopic evidence, and these elements have not met with acceptance. Those studies on the phosphorescence of spectra of the rare earths, especially gadolinium and europium, which he obtained from Urbain in Paris, were concluded in 1906. Crookes differed from Urbain as to the interpretation of the spectra and ascribed the intensification in the phosphorescence of the rare earths to some unidentified impurities in the calcium compounds with which the earths were mixed.

In 1912 Crookes investigated the spectrum of boron, and in 1914 the whole range of the spectrum of silicon. His specimens were presented by American factories. The researches on scandium—the eka-boron of Mendeleiev—resumed in 1908, were also largely spectroscopic at first. Crookes traced this element through 53 rare minerals, all of which, except wiikite, contained less than 0·01 per cent. of scandium, and he prepared the pure oxide Sc_2O_3 and a variety of scandium salts without isolating the metal, the existence of which had been predicted by Mendeleiev and confirmed by Nilson in 1879. The researches on the volatility of the platinum metals (1908 and 1912) concerned chiefly their utility for quantitative analysis. Nernst had found his directly-heated electric-resistance tubes of iridium very expensive, owing to loss of iridium. At dull-red heat Crookes' iridium crucibles were much less volatile and far more resistant than he had expected, though not superior to the less expensive and less heavy rhodium. But in the electric furnace, at 1,300 deg. C., iridium lost 7 per cent of its weight in 22 hours, ruthenium 25 per cent., while rhodium lost only 0·13 per cent. At Méker-burner temperature (about 900 deg. C.) most of the platinum metals proved very refractory.

On diamonds, and the action of radium on them, Sir William, assisted by Mr. Gardiner, gave a fascinating lecture at Kimberley, before the British Association, in 1905.* From considerations of the thermal data of carbon, carbon dioxide and other substances, he concluded, still in the same year, in a paper on "A New Formation of Diamond," that the critical point for carbon should be 5,800 deg. C. abs., with a corresponding pressure of 15 tons per sq. in., and that, at 4,400 deg. C. abs., 17 atmospheres should be sufficient to liquefy carbon. Such conditions would exist in guns, and microscopic crystals which Crookes detected in the residues from some explosions behaved chemically and optically like diamonds. Sir Charles Parsons made frequent references to Crookes' work on diamond when lecturing on "The Formation of Diamond" before the Institute of Metals a year ago.†

When experimenting in 1912 on the devitrification of an exhausted tube of silica glass (heated in an electric furnace), which became frosted and partly filled with air, Crookes noticed that the devitrified silica looked like a silica dish in which radium bromide had been evaporated. He did not follow the devitrification problem up, and the paper on "The Production of helium from radium," which he published in 1907, concerned rather other points. He fused beads of radium bromide to the ends of the platinum electrodes of a small vacuum tube and observed the evolutions of carbon dioxide on sparking. After a few months a helium line became visible in the spectrum, more exactly a line which in those days, when the nature of the several spectra of helium was being hotly contested, was attributed to "parhelium" and not to helium itself. The identity of helium and parhelium is no longer questioned now. But Crookes had, in 1905, investigated the action of sunlight on glass, and this he resumed in 1914. It is well known that common glass long exposed to strong sunlight assumes a violet amethyst tint, and that this colour change is ascribed to manganese, which is added to glass to counteract the greenish tint imparted to the glass by ferrous salts. Some glass samples sent to Crookes had been exposed to the sun, in Bolivia, 4,000 ft. above sea-level. They were almost black, but turned colourless again on being heated until the glass softened. The glass contained manganese, and the effect was apparently chemical and not superficial. In Kew Gardens the greenish glass of the hot-houses fades slowly, and may give way to a violet tint, due to manganese. Crookes did not believe that it was necessary to connect these radiation effects with radium. He observed, in 1914 again, however, that diamonds, garnets, gold, rare earths, zinc sulphide and screens of barium-platinocyanide acquired radio-activity when exposed to radium rays or kathode bombardment and became coloured. The colour and activity remained undiminished for years, but disappeared when the surface was mechanically removed.

One of the most recent researches in which Sir William was engaged to the last was conducted in connection with the Glass Workers' Cataract Committee of the Royal Society, since 1909, in his laboratory and in the Whitefriars Glass Works, London, with the assistance of Mr. H. Powell. The main object was to protect the men from the heat rays of the molten glass. Preliminary tests in Nuttall's Glass Bottle Works showed that the ultra-red rays were more to be feared than the ultra-violet, which are also dangerous, of course, as well as the visible rays, if very intense. Spectacles, it resulted, should be opaque to rays longer than 7,200 and shorter than 3,500 a.v. To combine this condition with transparency and absence of colour was the problem. A leadless soda flux was mixed with ceria and other rare earths, and with compounds of chromium, iron, nickel, cobalt, manganese, copper, lead, &c. Some 300 tints were tested, and 21 were recommended in the first communication on "Eye-preserving Glass for Spectacles."* The grey and neutral tints seem to be the most pleasant for wear. It should be noted that Crookes derived no financial benefit from the manufacture of these glasses, which was soon taken up.

In 1886 Crookes had presented his views on "The Genesis of the Elements," in his presidential address to the Chemical Section of the British Association Meeting at Birmingham. There was no direct evidence, he argued, of the transmutation of any supposed element into another, nor could we assert positively that our so-called elements had evolved from a primordial protyle; but the balance of evidence was in favour of the latter speculation.

As the cosmic protyle cooled, he suggested, granulation had set in and given us the various elements in a kind of Emerson-Reynolds pendulum swing curve. This is a zigzag curve, and the swing gradually declines as we proceed further down the curve on which the elements are arranged in the ascending order of their atomic weights, beginning with hydrogen and lithium at top and ending with uranium at the bottom. On the left side of the vertical axis are the paramagnetic elements; on the right side the diamagnetic; electropositive and electronegative groups alternate, electropositive elements being in the first swing on the left side, in the second swing on to the right side, and so on. The numerous gaps in Crookes' graphic representations do not mean, however, that important elements are missing (as the gaps do in Mendeleiev's periodic table), but that "at the birth of the elements there was an easy potentiality of the formation of an element which would fit into the place."

As President of the Bristol Meeting of the British Association in 1898, Crookes created a stir by his address on the national wheat stores, the exhaustion of the natural nitrate supply, and the necessity of finding means of fixing atmospheric nitrogen. In fuller form we find the same subject dealt with in his book on the wheat problem (1899 and 1905). In the further development of the nitrogen fixation problem Crookes did not take any part.

The other papers and books written by Crookes comprise "The Application of Disinfectants in Arresting the Spread of Cattle Plague," a part of the Third Report of the Cattle Plague Commission of 1866; "The Manufacture of Beetroot Sugar in England" (1870); "Handbook of Dyeing and Calico Printing" (1874); "Dyeing and Tissue Printing" (1882); books which, strangely enough, remained unique in the technical English literature for several decades, in spite of the great development of the dyeing industry; "Manual of Practical Assaying" (1873–81); "Select Methods in Chemical Analysis," which saw several editions (1871–76, 1905), and "The Reports of the Commission on the Quality of the Daily Samples of the Water Supply of London" (1880–1906). In this latter work he was associated with Sir James Dewar, and for some time also with Drs. Odling and Tidy. The

* See ENGINEERING, September 8, 1905, page 323.
† See ENGINEERING, May 3, 1918, pages 485–487.

* Philosophical Transactions of February, 1914.

analytical reports did not include any bacteriological tests. Crookes edited also a "Handbook of Aniline Colours" (1868), "A Practical Treatise on Metallurgy" (1870), "Chemical Technology" (1872), "Anthracene and its Derivatives" (1877), and "Ville's Artificial Manure" (1882). He, further, wrote on Sewage Disposal in 1899 and a book on Diamonds in 1909.

The Royal Society, to which he presented most of his papers, had admitted Crookes in 1863 and awarded him the Royal Medal in 1875, the Davy Medal in 1888, and the Copley Medal—the highest distinction the Society can confer—in 1904. The French Académie des Sciences granted him a gold medal and a purse of 3,000 francs in 1880 and made him a correspondant in 1906. His knighthood dated from the year 1897. After 1900 he was honorary secretary of the Royal Institution for a long period of years. Among other honorary appointments he held were those of President of the Chemical Society in 1887 and of the Institution of Electrical Engineers in 1890. The Swedish mineral crookesite, a selenide of copper and thallium, was named in his honour, and the dark space near the kathode of a discharge tube is known as the Crookes space.

Thus Sir William Crookes met with the fullest recognition of his work, and further signal honours came with the close of his life. He was created a Knight of the Order of Merit in 1910. The Royal Society, before which he had three times been invited to deliver the Bakerian lecture, appointed him Foreign Secretary for the period 1908 to 1912, and finally elected him President for the two years 1913 and 1914. The Society of Chemical Industry awarded him a gold medal and made him President in 1913, and medals and honorary fellowships were tendered by many foreign learned bodies.

Sir William has been likened to the alchemists, not inappropriately, perhaps. The retiring, reserved bearing, the austere mien, the deep devotion to metaphysical speculations and to matters occult, even the combination of his meditative disposition with a shrewd business sense, might harmonise with the suggestion. Always a hard and persevering worker whom obstacles stimulated rather than deterred, he seemed to possess a sound constitution, though he was by no means of robust appearance. Until the death, in 1916, of his wife—he had married Miss Ellen Humphreys, of Darlington, in 1856—always his companion for sixty years whenever circumstances permitted, he did not appear to age seriously. That loss affected him visibly. A year later he had a fall in his bedroom and was found unconscious one morning. To the amazement of his friends, however, he was about again after a few days. The end was peaceful. Two sons, Henry and Joseph, predeceased him. He leaves four sons and one daughter. The funeral took place yesterday, the 10th inst., at Brompton Cemetery.

THE VENTILATION PLANT OF THE SIMPLON TUNNEL.

THE original ventilation plant of the Simplon Tunnel, single in the first instance, was projected by the contractors, Messrs. Brandt, Brandau and Co., for the construction period rather than for the permanent tunnel service. Two ventilating fans, to be coupled in parallel or in series, were placed at each entrance, Brig in the north, Iselle in the south, each capable of giving 25 cub. m. of air per second at a pressure of 250 mm. of water. By the time the second tunnel was being constructed the transference of the power station to Massaboden had deprived the turbines driving the fans of their water, and the new ventilation plant was designed both for the second period of the building operation and for the permanent ventilation of the two tunnels. Although the old plant had admitted of working with compression or with suction from either tunnel end, the practice had been to force air into the tunnel at Brig and to withdraw it at Iselle. That practice necessitated the provision of a screen at either end.

The new project, which was actually taken in hand in October, 1913, provided for the erection of one ventilation plant only, and this plant was laid down at Brig. A selection had been made in favour of Brig because the central power station was there, because the whole organisation of the tunnel service was concentrated at that town, and because meteorological observations proved that the barometric pressure is in general higher at the northern entrance than at the southern entrance, so that the maintenance of an air current from north to south required less power than a current in the opposite direction.

The best solution of the problem would, of course, have been to have the current in each tunnel in the direction of the train motion, *i.e.*, to force air into tunnel No. I at Brig while withdrawing it from tunnel No. II at Brig. This plan was not adopted because it had been observed that, when the air was taken in at Iselle, all the iron in the tunnel structure rusted badly. The reason is meteorological. The air at the southern entrance is mostly warmer and more moist than at the northern inlet at Brig; air travelling to the north in the tunnel therefore deposits its moisture as it becomes cooled.

In order to reduce the air resistance to the train and the power demand on the ventilation plant it was decided to open the curtain at Brig, when a train starts at Iselle northwards in tunnel II and to shut the ventilation down for the time of the passage. The maximum air supply was fixed at 90 cub. m. per second for each tunnel, that is, at 180 cub. m. per second altogether, which is a large quantity. The velocity of the air current was fixed at 3 m. or 4 m. per second; a higher air velocity would be decidedly unpleasant to the men in the tunnel. Projects submitted were to conform to these main conditions. The chief firms whose tenders were accepted were Messrs. Sulzer Brothers, of Winterthur, the general contractors; Messrs. Brown, Boveri and Co., of Baden, for the electrical plant; and Messrs. J. Bolliger and Co., of Zürich, for the buildings and the ventilation trunks. In giving a general sketch of the new arrangements we follow a series of articles which Mr. F. Rothpletz, of Bern, has published in four recent issues of the *Schweizerische Bauzeitung*.

As regards the resistance which the air current would have to overcome, Messrs. Sulzer calculated that the resistance in the tunnel would amount to 60 mm. or 70 mm. of water; 4 mm. more were allowed for the resistance in the feeder trunks. A further factor to be considered was the barometric difference between the two tunnel openings. In general the barometer stands higher at Brig than at Iselle, the difference amounting to 115 mm. of water in exceptional cases. Cases where the atmospheric pressure was higher at Iselle than at Brig were also observed; they are rare, however, and this excess never exceeded 70 mm. The fluctuations in the barometric pressure were, in any case, sufficiently great, however, to make speed regulation of the ventilators desirable, and the specifications called therefore for the following normal (and minimum) figures for each of two ventilators: Air feed in cubic metres per second, 180; head in millimetres of water, 130 (70); effective horse-power at the ventilator shaft, 500 (300); revolutions per minute, 325 (240); efficiency, 0·72 (0·65). The average density of the air is 1·15.

Each ventilator is a fan, 3·5 m. external diameter, 1,564 mm. width, with a central suction opening 2,600 mm. in diameter; the six parallel rows of buckets, built up of wrought-iron blades and partitions, take up 1,284 mm. of the width of the wheel; the hub is of cast iron. The two fans have been mounted in the same building, the one above the other; the air conduit from the lower fan is therefore steeper than that of the other, and the two conduits unite at an acute angle at which the main valve is hinged. This valve, 7·85 m. long and 4·5 m. wide, closes either the lower or the upper conduit, being raised or lowered by machinery or by hand with the aid of two wire ropes. When only one fan is working, this valve closes the other channel; when both fans are run in series, the one draws in air through its suction gate and sends it through the second fan; one conduit thus remains again closed. There are further four valves for the accessory air channels. Each fan weighs 12 tons; the electric motor driving it weighs 11 tons, and the regulating devices, transformers, switches, &c., more than double the latter figure. The casing of each fan is brickwork, except the first helical portion which is made of sheet iron; the two conduits are square in section, the side being 4·5 m.

Each fan is directly coupled with an asynchronous three-phase motor which is fed with railway currents of 3,200 volts at 16⅔ periods. The speed regulation is effected on the Brown-Boveri-Scherbius system; the rotor current of the motor is not absorbed by resistance, but serves to feed a three-phase collector motor which is coupled with an induction generator sending its current back into the mains; this regulating apparatus alone weighs 9·5 tons. The whole building is a ferro-concrete structure. The lower fan rests on a massive block of concrete; the upper fan is mounted on ferro-concrete beams, but the base is separated from the other parts of the building.

We mentioned that each northern tunnel entrance can be closed by a screen or curtain. For this purpose a portal frame of iron is built into the brickwork, about 2 m. from each tunnel end; the curtain is suspended in the frame by means of chains and can be raised or lowered by means of electric devices or by hand. The lower edge of the curtain, which is made of impregnated sailcloth, is held by a rope of soft copper wire; the track in the plane of the frame is levelled up to the railhead with concrete, and the copper rope rests fairly airtight on the concrete surface when the curtain is lowered. Should accidentally the curtain be down when a train is approaching, the engine would burst through the curtain and the rope of soft copper wire without endangering the train. The curtain is automatically operated with the aid of track contacts.

The cost of the whole ventilation plant amounted to 486,973 francs; earth-and brickwork and mechanical appliances cost 139,169 francs, the fans and electrical apparatus 187,343 francs, the building 100,496 francs, and the trunks from the ventilation building to the tunnels 59,965 francs. The main installation work was completed in 1914. At the acceptance tests the specified performances were exceeded, although the consumption of electric energy was below the calculated figure; the full air-pressure head was not quite realised, however. The air temperature in tunnel I was lowered, from 29 deg. and 30 deg. C. with the old ventilation, to 23 deg. and 25 deg. C. with the new ventilation; these temperatures were measured at distances of 7 km. and 8 km. respectively from the north entrance. At the south entrance observations could not be conducted during the war. It has been noticed that the air-pressure heads adapt themselves to fluctuations in the barometric pressures; but tunnel II is not yet quite completed and final results cannot be stated at present.

H.M. BATTLE CRUISERS "REPULSE" AND "RENOWN."

IN the early months of the War the need for additional battle cruisers of very high speed and armed with big guns, became more and more apparent, both to deal with raids on our coasts by enemy battle cruisers and with possible raids further afield. The value of this type of ship was also most clearly demonstrated at the Battle of the Falkland Isles. The British Admiralty therefore decided on the advice of Lord Fisher in January, 1915, to lay down a new type of cruiser, of great length and limited draft, and of very much increased speed, to meet this need. The battle cruisers Repulse and Renown were therefore ordered, the former from Messrs. John Brown and Co., Ltd., Clydebank, and the latter from the Fairfield Shipbuilding and Engineering Company, Ltd., Glasgow, at the beginning of January, 1915. Fig. 1 on Plate XXIX shows the Renown on trial, while Fig. 2 on the same plate illustrates the Repulse as completed. Both ships are alike in every respect, and were the largest and most noteworthy warships added to the British Fleet during the War. Our series of illustrations of the Repulse and her machinery on Plates XXX to XXXII and on pages 462 and 474 will, therefore, be studied with interest.

The first keel plate of the Repulse was laid on January 25, 1915 (Lord Fisher's birthday) and

H.M. BATTLE CRUISER "REPULSE."

CONSTRUCTED BY MESSRS. JOHN BROWN AND CO., LIMITED, CLYDEBANK.

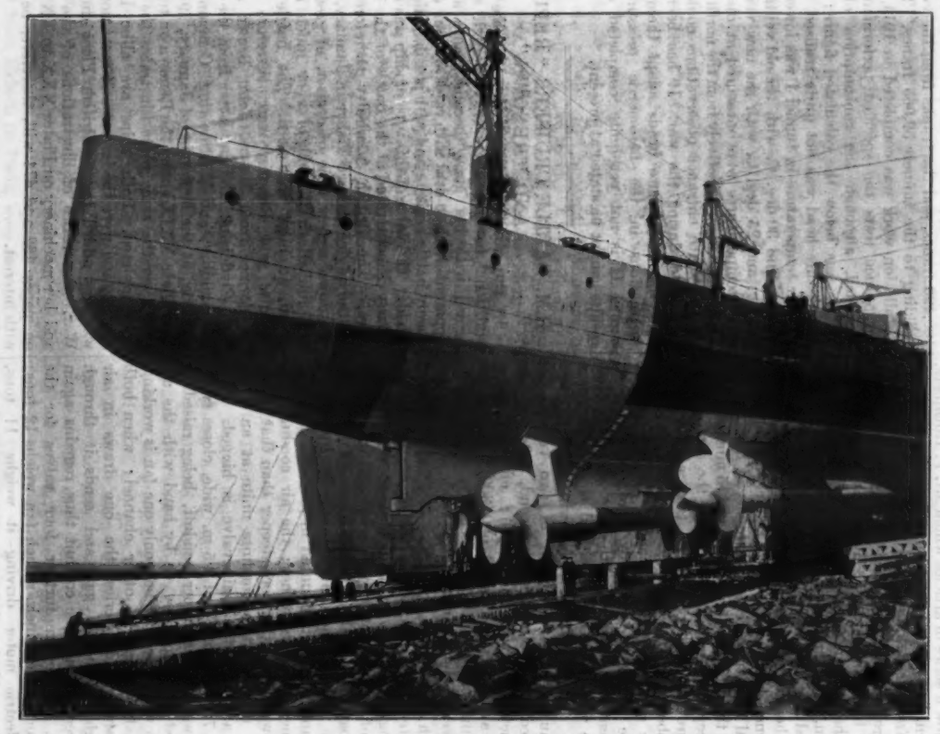


FIG. 7. READY FOR LAUNCHING; JANUARY 8, 1916.

FIG. 8. THE LAUNCH, JANUARY 8, 1916; ELEVEN MONTHS AFTER THE KEEL WAS LAID.

by the end of March, 900 tons of steel materials had been built into the structure. The stage of construction reached on April 14 is shown by Fig. 3 on Plate XXX. By dint of great effort and willing co-operation on the part of the workmen, 1,600 tons were worked into the hull in each of the next three months, and the ship was into good shape up to the Protective Deck (Fig. 4) by the time His Majesty, King George V visited the works in the early summer of that year. Continuing the pressure throughout the summer and autumn (Fig. 5), the vessel was brought to the launching stage before the works stopped for the New Year holidays, and was successfully launched on January 8, 1916, the christening ceremony being performed by the Duchess of Montrose. Fig. 7 annexed shows the vessel ready for launching, and Fig. 8, also on this page, the launch. The immense propelling machinery and main armament was rapidly placed on board (Figs. 6, 9, 11 and 12 on Plates XXX to XXXII and Figs. 13 to 16 on pages 463 and 474); the vessel closed up; the accommodation, equipment, electrical work completed; and the Repulse left Clydebank Yard, a commissioned ship, on August 14, 1916, or in 19½ months from the date when the requisite information was received by Messrs. John Brown and Co., and the Fairfield Company to proceed with the detailed drawings in conjunction with the Admiralty officials, and to send out orders for material.

On a preliminary run to Ailsa Craig immediately after the vessel reached the Tail-of-the-Bank, the machinery was gradually worked up to 107,000 s.h.p., and on the following day, during the four hours' trial, the mean horse power developed for the first two hours, was 117,000 and for the subsequent two hours 121,000. Further trials were carried out in the Firth of Clyde when the vessel was loaded to about 30,000 tons displacement, and over a measured course a speed of nearly 32 knots was attained, the machinery developing over 119,000 s.h.p.

The Repulse was the largest and most powerful warship in the world at the time, her length being 790 ft., breadth 90 ft., and depth to upper deck 41 ft., with a normal displacement of about 27,000 tons. As is shown by our illustration on Plate XXIX, the vessels present a striking and graceful appearance, having a long forecastle, high shelter deck, and central house under the navigating bridges, two large oval funnels, and two tripod masts fitted with top masts. The great length in proportion to depth gives the appearance of a large type of light cruiser rather than a battle cruiser, but on closer examination, the two barbettes, each having a pair of 15 in. guns highly mounted for ahead attack, equal in power to those fitted in the Super-Dreadnoughts, and a similar pair of 15 in. guns mounted in a turret aft, give a strong impression of the great size of the vessel. These guns are each arranged to train through 150 deg. on either side of the middle line, and give a concentrated broadside fire, equal to 75 per cent. of that of the latest battleships, thus making the vessel very powerful in attack.

The secondary armament consists of 17, 4 in. B.L. guns, 15 of these being arranged on triple mountings, two sets on the conning tower platform level on each side of the forward funnel, and three sets on the middle line on the flying and the shelter deck level. The single 4 in. B.L. guns are placed on the shelter deck, on each side abreast of the conning tower, with a training sweep of 155 deg. Two 3 in. high angle guns are mounted on pedestals on the shelter deck abreast after the funnel, four 3 pdr. Q.F. guns on the same deck abreast the forward funnel, and five machine guns. In conjunction with these guns, there are fitted on platforms attached to the funnels, six 36 in. single searchlight projectors, two similar projectors on the compass platform, and two 24 in. single signalling searchlights at the after end of the conning tower platform. The vessel is fitted with two 21 in. under-water broadside torpedo tubes, placed

THE TURBINES OF H.M.S. "REPULSE."

CONSTRUCTED BY MESSRS. JOHN BROWN AND CO., LIMITED, CLYDEBANK.

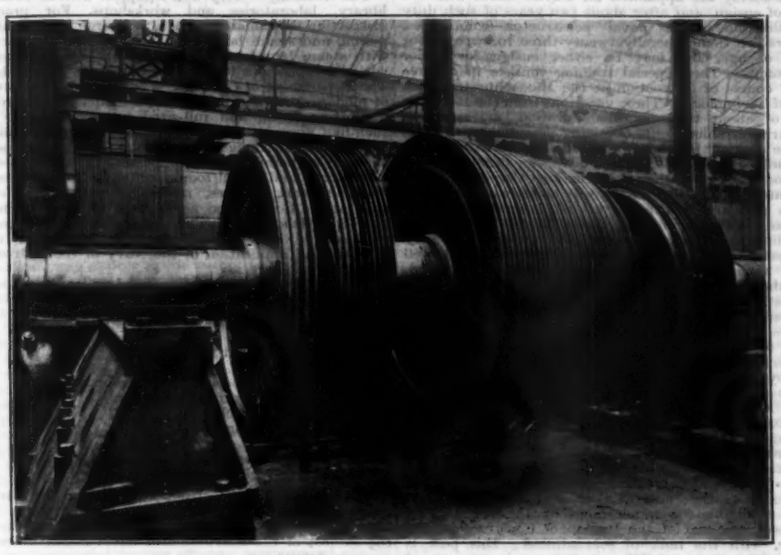


FIG. 13. INTERMEDIATE-PRESSURE AHEAD AND HIGH-PRESSURE ASTERN ROTORS.

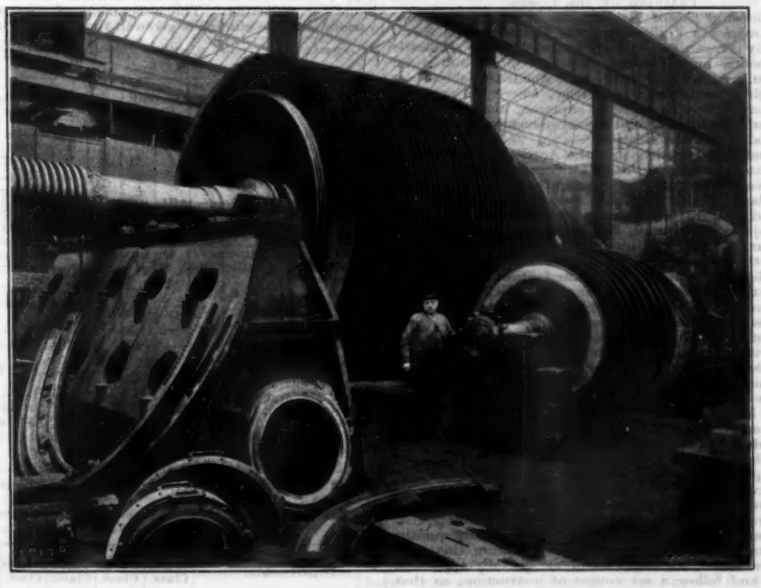


FIG. 14. COMPARISON BETWEEN THE LOW-PRESSURE TURBINES AS FITTED IN THE "REPULSE," WITH DIRECT DRIVING TURBINES, AND THE LOW-PRESSURE TURBINES AS FITTED IN A LARGE HIGH-POWERED FIRST-CLASS CRUISER WITH GEARED TURBINES. POWER RATIO 3:2.

in a compartment between the platform and the lower deck forward of the forward magazine; stowage is provided for 10 torpedoes.

The conning tower is of oval form having armour 10 in. thick, with an inner gun control tower with revolving hood and armoured rangefinder. An armoured torpedo control tower, with revolving hood and rangefinder for controlling the fire of the torpedoes, is placed on the after flying deck. In addition to these towers, which are situated in commanding positions, there are fitted on the foremast high above the navigating platforms, a spotting top, a 15 in. gun director platform, and a 4 in. gun director platform; also a director platform and rangefinder for anti-aircraft guns on the main mast; and a signal distributing station in the armoured house on the shelter deck under the main conning tower. The intelligence and de-coding offices are in similarly protected houses placed on the forecastle and shelter decks respectively.

The vessel is minutely sub-divided, having six boiler rooms, four engine rooms, and a cellular double bottom, extending from the middle line right round the side and under the main or protective deck. A longitudinal bulkhead forming the boundary of the oil tanks extends alongside the engine rooms, boiler rooms and magazines, with an inner bulkhead forming an air space for the extent of the boiler rooms.

The armour consists of a main belt about 9 ft. 6 in. wide extending from abreast the after barbette to forward, and aft of these positions for a further length of 84 ft. forward, and 62 ft. aft of reduced thickness. The armour belt is finished off by a transverse armour bulkhead forward and aft, and two additional transverse armour bulkheads are fitted to resist end on fire. The maximum thickness of the armour of the barbettes is 7 in. The forward conning tower armour is 10 in. thick, and the torpedo control tower 3 in. thick. The main or protective deck is 2 in. thick on the slopes with an additional strake of 2 in. high tension protective plating in the vicinity of the water line. The lower deck aft is 3½ in. thick over steering gear.

Structurally, the vessel is very substantially built, the shell plating of the topsides and the forecastle deck consisting of two thicknesses of high tensile steel of a total thickness of 1¼ in., and the bottom plating is generally 1 in. thick, tapered at the ends.

The chart house, admiral's and captain's sea cabins, navigating officer's cabin, are situated on the platform and shelter deck forward. The Repulse was completed as a flagship, the admiral's cabins being in the deck house on the after end of the forecastle deck. The ward room, captain's cabins, and principal officers' accommodation, offices, &c., are on the upper deck aft. The gun room and junior officers' cabins are placed on the main deck aft of midships. The mess decks for the crew are on the upper deck amidships and forward, and on the main deck amidships; the sick bay and operating rooms, and lavatories in connection therewith, are on the upper deck forward; the wash places for crew are on the main deck abreast the boiler rooms and forward.

The equipment of the vessel is very complete; the electric generating machinery consists of two sets of steam-driven reciprocating engines, each of 200 kw.; one turbo and one Diesel engine-driven generators of equal power placed in separate compartments forward and aft; electric boat winches, ammunition and deck winches; warping capstan; auxiliary steering gear; ventilating fans for machinery spaces and for working compartments and living quarters; electric heating for cabins, magazine cooling and icemaking plant; electric pumps for fresh water and bilge purposes; three sets of wireless installation; eight lifts for engine and boiler rooms; electric power for driving workshop machinery; a very complete installation of telephones and alarm bells; also the electrical equipment in connection with fire control, transmission of range and training of guns, danger signals, torpedo control and firing gear, and gyro-compasses. The capstan engines and cable holders are of the usual steam-driven type for the forward cable gear. The steam steering engines, controlled by telemotors, are placed on the after bulkhead in the engine room, and are connected up by shafting and gearing to a powerful set of screw steering gear operating a single balanced rudder.

The propelling machinery consists of Brown-Curtis turbines driving four shafts, two on each side of the ship. They are the largest direct-drive turbines built in the world. Their size is shown by Fig. 12, on Plate XXXII, of a high pressure and low pressure set being prepared in the shops for balancing, while Fig. 11 showing the stern tube shaft, 70 ft. 3 in. in length, in a lath is equally impressive.

The turbines are placed in two engine rooms side by side, divided by a middle line bulkhead. In each engine room are three turbines driving the two shafts, the high pressure ahead and low pressure ahead being on the inner shaft and rigidly connected with each other (Fig. 12 on Plate XXXII), and the intermediate pressure ahead on the wing shaft. Incorporated in the same casing as the intermediate pressure ahead turbine is a high pressure astern turbine (Fig. 13) and with the low pressure ahead turbine is a low pressure astern turbine (Fig. 14). In this view there is seen alongside the low pressure turbine for a geared set of about three-fourths of the power and the effect on size of increasing the number of revolutions where gearing is fitted between the turbine and propeller will be appreciated.

The high pressure ahead turbine consists of two wheels, each carrying three rows of blades, the pitch circle diameter of these blades being 10 ft. 6 in. The intermediate pressure ahead turbine (Fig. 13) consists of two stages of two rows of blades each, and a short drum of 12 rows of blades; then a second portion of two stages of two rows each; and a drum of 31 rows. The pitch circle diameter of

these varies from 9 ft. 3 in. to 10 ft. The low pressure ahead rotor (Fig. 14) consists of a drum portion of 34 rows, with a pitch circle diameter of 12 ft. The last blades are 26 in. in length and 1¾ in. wide.

The astern turbines consist of two stages of four rows each and a drum of six rows forming the high pressure astern turbine and a wheel of three rows and a drum of nine rows forming the low pressure astern turbine. The pitch circle diameter of the high pressure astern turbine is 10 ft. and of the low pressure astern 11 ft.

The propeller thrust in each case is nearly balanced by the steam thrust arranged in the turbine, so that no main thrust block is necessary, but only a comparatively small block on each line of shafting (Fig. 14). Each of these blocks has a thrust surface of 4,370 sq. in. on 16 collars. In order to obtain this balance in the intermediate pressure turbine, one of Mr. Curtis' latest patents was introduced, namely, to take the steam a short distance along the turbine, passing it in the forward direction, and then, by external passages, to cause it to re-enter the turbine and to travel aft for the remainder of the length of the rotor.

The intermediate shafting is 18¼ in. diameter with an 11 in. hole, and the propeller shafts are 24 in. diameter with a 19 in. hole, these being cased with gunmetal liners in the stern tubes and main brackets.

The condensers, two for each set of engines, are placed in two compartments immediately aft of the main engine rooms, with the eduction pipes passing through the transverse bulkhead. The surface of each condenser is 19,225 sq. ft., or a total of 76,900 sq. ft. for all the condensers. In the condenser room are the main circulating pumps, two per set of main engines, the evaporators and distillers, &c. The main air pumps are in the main engine room, so as to be under the control of the engineer of the watch. The forced lubrication pumps for the turbine bearings are also in the engine rooms, together with the necessary oil coolers, filters, &c., while the smaller forced lubrication pumps, coolers, &c., for the shaft bearings are in the condenser rooms.

Steam is supplied by 42 boilers of the Babcock & Wilcox type, these being entirely oil fuel fired and working at a pressure of 250 lbs. per square inch. The total combustion chamber space of the boilers is 23,310 cub. ft., and the total heating surface of all the boilers is 157,206 sq. ft. The boilers are all alike, each of 22 sections wide, 8 ft. 1 in. between headers. The bottom tubes are 3⅜ in. external diameter each and the remainder of the tubes, 1¾ in. external diameter. The vessel has two funnels, the forward one serving 22 boilers and the after one 20 boilers. The forward funnel is 25 ft. by 16 ft. 6 in. and the after one is 13 ft. by 16 ft. 6 in.

The auxiliary machinery throughout the vessel is in accordance with the usual Admiralty practice.

THE NAVAL CONSTRUCTION CORPS OF THE UNITED STATES NAVY.*

By S. V. GOODALL, R.C.N.C., M.B.E., Member.

THE Navy of the United States of America is now second to none, except that of Great Britain. During the war this Navy was very considerably enlarged, and the present building programme is greater than that of any other Power. A study of the constitution, training and work of the Corps on which the burden of the satisfactory production of this material so largely rests is, therefore, worth while; but particularly so, since the senior officers of the Corps have been trained in British, French or German schools, and have had some inside knowledge of the Construction Corps of European navies. It is but natural to assume that the United States Construction Corps represents the adaptation to American conditions of all that was considered best in the training and organisation of these other corps.

CONSTITUTION OF THE CORPS.

Officers of the Construction Corps are selected from line officers. The reputation of the Corps and the conditions of service are sufficient to attract the best line officers of each class, and applications for entry are not approved unless they come from men of the highest character and attainments.

A constructor, therefore, commences his service career as a midshipman at the United States Naval Academy, Annapolis, Md. To qualify for entry, a certain educational and physical standard is necessary, and a nomination must be obtained. The course at the Academy, which is fully described later, lasts four years, nine months of which are spent at sea. Graduates from the Academy are appointed for service afloat with the rank of ensign, and after about two years of such duty specialisation as a naval constructor commences. Officers are then generally twenty-three to twenty-four years of age, and may be either ensigns or junior lieutenants. Their special training consists in a three years' course of instruction at the Massachusetts Institute of Technology. Three vacations from the institute, each of about three months' duration, are spent at industrial establishments obtaining practical experience. At the end of this time, provided the course has been satisfactorily completed, officers, who have now become lieutenants, enter the Construction Corps and are appointed for duty to navy yards or elsewhere.*

The pay and allowances of naval constructors are the same as that of line officers of the same rank; according to British standards junior officers are very well paid, and officers of intermediate grades fairly well paid. Senior officers, however, are poorly remunerated, with the inevitable result that the United States Navy has lost the services of some of its best naval constructors, who have been attracted to the employment of private corporations.

Up to and including the rank of lieutenant-commander, naval constructors are promoted by seniority side by side with their class-mates of the line—an examination must be passed to qualify for each promotion. Above the rank of lieutenant-commander, constructors are promoted by selection as vacancies occur, but, again, for each grade up to that of captain, an examination must be passed. The selection board and the examining board are composed entirely of senior officers of the Construction Corps. Any member of the Corps of the rank of lieutenant-commander and above is eligible for appointment by the Secretary of the Navy as Chief of the Bureau of Construction and Repair, with the rank of rear-admiral; this post is held for four years, and if the appointment is not renewed and the holder remains in the Corps, he returns to his appropriate rank. Retirement from the corps is compulsory at the age of sixty-four.

TRAINING OF THE CORPS.

1. *Course at United States Naval Academy, Annapolis.*—In America a graduate of the United States Naval Academy is regarded as a man, not only of high scholastic attainments, but of sound, physical, moral and social qualities. And rightly so. The Academy is really a thoroughly democratic university, where the spirit of strict naval discipline reigns supreme, and the course provides for physical and social development as well as a good technical education.

A candidate for entry into the Academy must obtain a nomination from the President, Secretary of the Navy, or a member of Congress; such nominations are open to all classes.† He must pass a strict physical examination and a fairly simple mental examination, in which the subjects are reading and writing, spelling, English grammar, geography, United States history, arithmetic, algebra through quadratic equations, and plane geometry. A candidate is eligible for examination the day he attains the age of sixteen years and ineligible the day he becomes twenty years of age.

Successful candidates, after taking an oath to serve for eight years in the United States service, enter in June with the rank of midshipmen, and for the first four months are the sole occupants of the Academy, the senior midshipmen being absent on the summer practice cruise. During this time the instruction is mainly in infantry and rifle range drill, seamanship, marine engineering, athletics and a little English. This is considered to be a valuable period, during which the junior class is alone to "shake down" and become used to discipline.

The course occupies four years. The academic year begins on October 1 and ends May 31, and is divided into terms of four months each. After the first year midshipmen embark in various warships for three months each summer for a practice cruise. During this time they are under the supervision of specially-appointed officers and follow a set course of instruction, so that when they graduate they have spent nine months at sea, becoming accustomed to life and duties afloat.

During the course marks are assigned for class work, monthly, semi-annual and annual examinations. Deductions from these marks are made for misconduct and petty offences. The total at the end of the course decides the seniority of the officer in the Navy Register. Midshipmen are also examined annually by medical and dental officers. Any midshipmen who are unusually backward in their work, or who indicate that they are unlikely to make efficient officers, are removed. This practice is strictly enforced, as exemplified by the example of one year, selected at random, when 145 midshipmen of the senior class graduated and were appointed ensigns, and 86 of all four classes resigned. These incentives make the course, which is itself set to be strenuous, a time of steady hard work and continued application.

The Academy is very well equipped with an excellent library, laboratories and workshops. For practical instruction in seamanship there is a large fleet of sailing, pulling and steam boats, and fleet tactics are practised with steam launches run entirely by the midshipmen, who also operate a tug boat assigned to the Academy. The Department of Ordnance is equipped with a battery of modern 5 in. and 6 in. guns, a model conning tower, a plotting room, and full-sized torpedoes, mines and such-like apparatus. A model ship is installed in the Department of Navigation, which is used for instruction in the adjustment of compasses. The engineering laboratories and model rooms contain a large number of machine tools, engines, motors, dynamos and other apparatus. Compressed air is used for working many of the models. All this equipment is so arranged as to stimulate interest and concentrate attention upon the practical application in the Navy of the instruction that is given.

The branches of study are grouped under the following departments:—

1. Discipline.
2. Seamanship.
3. Ordnance and gunnery.
4. Navigation.
5. Marine engineering and naval construction.
6. Mathematics and mechanics.
7. Physics and chemistry.
8. Electrical engineering.
9. English.
10. Modern languages.
11. Naval hygiene and physiology.

Particulars of the instruction given in the various departments are indicated in Appendix I. These particulars have been abbreviated, but those germane to the subject of the instruction of naval constructors are given in detail.

The working week is divided roughly into 32 hours for class instruction; 12 hours for evening study when lessons to be heard the following day are prepared; 6 to 7 hours for drill or practical work, and about 20 hours for recreation. The assignment of time to the various subjects studied is given in the following tables:

1. *Number of Periods* of Study given each Week to Class Work.*

Departments.	Senior Class.		Second Class.		Third Class.		Junior Class.		Total
	First Term.	Second Term.	First Term.	Second Term.	First Term.	Second Term.	First Term.	Second Term.	
Seamanship ..	3	4	—	—	—	—	—	—	7
Ordnance and gunnery ..	4	3	—	2	—	—	—	—	9
Navigation ..	3	3	—	5	—	—	—	—	11
Marine engineering and naval construction ..	2	3	4	5	3	3	3	3	26
Mathematics and mechanics ..	—	—	5	—	5	5	6	6	27
Electrical engineering and physics	3	3	3	3	4	4	—	—	20
English	—	—	2	—	2	2	4	4	14
Modern languages	1	1	2	1	2	2	3	3	16
Hygiene	1	—	—	—	—	—	—	—	1

* For class studies a period is roughly two hours.

2. *Number of Periods† of Drill or Practical Instruction given during a Year.*

Departments.	Senior Class.	Second Class.	Third Class.	Junior Class.	Total.
Executive	31	37	40	44	152
Seamanship	16	22	25	32	95
Ordnance	24	22	15	4	65
Navigation	4	—	—	—	4
Marine engineering and naval construction ..	24	24	24	—	72
Electrical engineering ..	9	3	—	—	12
Gymnastics	—	—	—	28	80
Dancing	—	—	—	16	16

† For drills a period is roughly 1½ hours.

The value attached to the various subjects of instruction is shown by the table of marks allotted for the work during the four years, given in the next column.

The following critical remarks on the instruction given at the Naval Academy apply to the course as one for embryo naval constructors. The author is not concerned with criticism of the course as one of preparation for service as a naval officer.

The advantages of this common course for midshipmen who are to become engineer, gunnery, torpedo, navigating, watch officers or naval constructors, are that for the first four years of their service all these officers are subject to the same strict discipline and learn that, whatever branch they may serve in later, their work is for the general good of the Navy. As a result, they all have a similar outlook, and later in life there

* Paper read before the Institution of Naval Architects, April 9, 1919. Space will not permit us to publish the appendices.

* The course outlined above has been recently modified slightly. On the completion of two years at sea, a short post-graduate course in naval construction is taken at the Naval Academy. Particulars of this course are given in Appendix II. This is preparatory to the course at the Institute of Technology, which was slightly modified accordingly. Only brief mention is made of this post-graduate course, as the training fully outlined later is more representative of the general scheme so far adopted.

† The law allows at the Naval Academy five midshipmen for each senator, representative and delegate in Congress, two for the District of Columbia, and one for Porto Rico. In addition, the President can nominate 15 annually from the country at large, and the Secretary of the Navy may make 100 appointments annually from enlisted men.

exists between the various branches a feeling of fellowship making for co-operation and smooth working. Actual service afloat during the period of training is a very valuable experience for the future naval constructor.

Departments.	Junior Class.	Third Class.	Second Class.	Senior Class.	Total.
Efficiency	0	1	5	8	14
Practice cruise	—	1	2	3	6
Seamanship	—	—	—	15	15
Ordnance	—	—	3	15	18
Navigation	—	—	9	13	22
Marine engineering and naval construction ..	4	7	14	10	35
Mathematics and mechanics	7	11	8	—	26
Electrical engineering and physics	—	9	11	12	32
English	5	5	3	—	13
Languages	4	6	5	3	18
Hygiene	—	—	—	1	1
Total	20	40	60	80	200

The disadvantages appear to the author to be that the future executive officer gives an unnecessarily large amount of his time to the study of naval construction and allied subjects, while the future naval constructor gives too much of his time to matters which, although of interest, are not essential in the practice of his profession. As the average age at entry is seventeen to eighteen years, specialisation is deferred to an unduly late period. While it may be claimed that this results in the possession of a broader outlook, such an advantage is dearly purchased at the cost of lack of intimate knowledge. In a course covering so many subjects it is inevitable that the knowledge obtained of many subjects is a mere smattering. This is particularly so in the case of practical instruction in the workshops. The authorities do not claim that they attempt to produce a skilled mechanic, but it is doubtful whether the time given is sufficient to enable a graduate to have that knowledge of mechanical processes which, in the case of a naval constructor, is essential for the efficient performance of duties which are bound to devolve upon him during his service career. Moreover, in obtaining this limited knowledge of practical work in the workshops of an academy instead of those of a dockyard or such-like establishment, he loses the opportunity of making that intimate acquaintance with workmen which is invaluable to him later. It is admitted that this latter objection is of less weight in the United States than it would be in Great Britain, and that practical work is done during the summer cruises, but there is much difference between the workshops of a ship and those of a dockyard and a very great difference between the attitude of a bluejacket to a midshipman and a dockyard workman to an apprentice.

My thanks are due to Rear-Admiral E. W. Eberle, Superintendent, and Commander J. L. Hileman, Head of the Department of Marine Engineering and Naval Construction, for information regarding the course at the Academy.

2. *Course at the Massachusetts Institute of Technology.*—This institute is the foremost establishment of the kind in the United States. In its courses the authorities aim to develop the power to deal effectively with new engineering problems rather than to impart an extensive knowledge of details. While instruction is largely personal, students are assigned problems for independent solution. A moderate participation in social and athletic activities is encouraged, but the standard of scholarship demanded prevents an excessive devotion to such pursuits.

Examinations are held twice a year, but, compared to those of British educational institutions, these tests are not severe, and the authorities attach less importance to them. It is admitted that discipline is less strict in consequence, but this policy is intentional and is advocated on the ground that it is difficult to set examinations in subjects comprising the various courses without including a number of problems that are artificial, and if students believe that they will be judged largely on results of such examinations they devote too much time to the acquirement of facility in dealing with such problems rather than to a thorough acquisition of broad principles.

A description of the Institute's laboratories, libraries and drawing-offices is beyond the scope of this paper. Suffice it to say that they are up to the highest standards.

The officers of the Department of Naval Architecture and Marine Engineering are :—

Cecil H. Peabody, S.B., Professor of Naval Architecture and Marine Engineering.

William Hovgaard, Professor of Naval Design and Construction.

Edwin B. Wilson, Ph.D., Professor of Mathematical Physics.

Joseph C. Riley, S.B., Major U.S.A., Associate Professor of Heat Engineering.

Henry W. K. Keith, S.B., Assistant Professor of Naval Architecture.

George Owen, S.B., Assistant Professor of Naval Architecture.

And five instructors.

Located at an important seaport, the Institute possesses an advantageous position for students of naval architecture and marine engineering. Facilities are afforded for visiting the Boston Navy Yard, the local shipyards and engine works, and ships of all types. Opportunities are provided for attendance at trials of ships and tests of boilers and engines that are carried out in the neighbourhood. Some of the speed trials and rudder tests made by students under the direction of the Institute's staff have given results of considerable scientific value.

The Department has a well-equipped shop, with special machinery, in which instruction if given in making ships' models. A wind-tunnel is provided for work in applied aero-dynamics, and under a recent bequest the Pratt Memorial Building will be erected and will, it is hoped, contain an experiment tank.

The drawing-offices of the department are well equipped with planimeters, integrators, integraphs and calculating machines. There are four glass-topped tables for fairing ships' lines, which are laid down on a floor in accordance with mould loft practice. There is a collection of complete sets of drawings and detailed particulars of ships and their machinery, both merchant ships and warships, which are available for reference.

The department possesses its own library, containing technical periodicals as well as standard and recent works on naval architecture and marine engineering. This is in addition to the other large libraries belonging to the Institute.

In naval architecture and marine engineering the Institute offers a four-year undergraduate course, leading to the degree of Bachelor of Science, and a further one-year graduate course leading to the degree of Master of Science. Consequently, naval constructors during this period of their training are in close touch with men whose present and future interests are in merchant shipbuilding. This, and the fact that their course is, in some respects, common with that of the ordinary students of naval architecture, serves to broaden their outlook and may lead to valuable co-operation later, as it did in fact, during the war.

The course for naval constructors extends over three years. It covers the work of the five years' course, which is capable of concentration into a three years' period on account of the training the officers have already received. For the satisfactory completion of the course the degree of Master of Science is given.

Particulars of the course are given in Appendix III. If this be carefully considered there will arise a feeling of surprise at the small amount of time given to pure and applied mathematics, and the author is strongly of opinion that the course suffers by this omission. While it is admitted that naval constructors on entering the Institute of Technology have already received a certain amount of mathematical training and have reached an age when the development of a mathematical mind is more difficult, it is firmly held that the habits of thought and deduction that come from a careful training in mathematics alone justify the devotion of a large amount of time to this subject, apart from the value of applied mathematics in actual scientific problems which a naval constructor is called upon to solve during his professional career.

At first sight it might appear that strength of materials, mechanism and such subjects generally denoted by the broad term applied mechanics, do not figure largely in the curriculum, but these are also dealt with in the courses on naval architecture and electrical and marine engineering. Moreover, naval constructors are considered to possess a fair knowledge of these subjects before they join the Institute of Technology.

Instruction in such subjects as the principles of accounting, factory management, economics of corporations, industrial management and business law is a noteworthy feature of the course. In many of the posts which a naval constructor is called upon to fill, a knowledge of the principles of scientific organisation and management is of great value. In lieu of these subjects a course in aeronautical engineering may be taken by naval constructors who anticipate specialising in this work. Theoretical instruction in the dynamics of solids and fluids as applied to the motion of aeroplanes and airships is accompanied by practical work in the aerodynamical laboratory. Lectures are also given on the design of aeroplanes, airships and aerial propellers, and a design is prepared of one type of aeroplane and of a dirigible, with propellers adapted for each case.

The importance assigned to marine and electrical engineering is the result of much consideration. Those responsible for these courses hold that a proper co-ordination of the design of a warship and its propelling machinery can be attained only when a naval constructor is familiar with both naval architecture and marine engineering, hence instruction is given in thermodynamics, heat engineering, steam turbines and marine engineering. To some extent the same reason holds for the course in electrical engineering, for in all United States capital ships now under construction the propellers are driven by electric motors. But, in addition to this, electrical power is relied upon for auxiliary purposes in United States warships to a greater extent than in the British service, and the Construction Corps is responsible for the design and manufacture of many of these electrical machines.

It can be seen that those who prepared this scheme of training are fully cognisant of their difficulties. A naval constructor, besides being a specialist on ship design and construction, must have a knowledge of almost every form of engineering, and it is hard to decide what can be omitted from his course of training with least harm. The author cannot help feeling that in this course for naval constructors the Institute's excellent maxim in favour of liberal studies of a broad character rather than courses on highly-specialised subjects has been somewhat hidden in the background, and an attempt is made to impart at an educational institution knowledge and experience which can be far better obtained in the shipyard and machine shop.

Instruction during the Summer Vacations of the Institute of Technology.—The annual session lasts from the latter end of September to the middle of June, and is divided into two terms. The break between these terms occurs at the end of January, when there is a week's recess. There is also a recess of one week at Christmas and a few days towards the end of April.

During the summer vacation naval constructors are appointed for training to a Navy yard, private shipbuilding establishment or a large manufacturing concern, where they become acquainted with practical shipbuilding, marine and electrical engineering. As an example of the way in which this time is spent, the case of one officer is given who spent a part of three months at the United States Navy Yard, Brooklyn; a part at the yard of the New York Shipbuilding Company, Camden, N.J., and a part at the works of the General Electric Company, Schenectady. While at these establishments the officers do actual work, besides receiving personal advice and instruction from leading men and foremen. The officials of the General Electric Company particularly take an interest in the officers sent to their works. They give them lectures and allow free access to research laboratories.

The amount of time a naval constructor spends on this part of his training may be from six to nine months, according to the date he leaves his ship prior to joining the Institute of Technology. While most British naval constructors will agree that this period is far too short, it must be admitted that the best possible use is made of the time.

My thanks are due to Professors Peabody and Hovgaard for assistance and information regarding the course at the Institute of Technology.

Strength and Service of the Corps.

In April, 1917, when the United States entered the war, the strength of the Corps was as follows :—

Admirals	2
Captains	7
Commanders	11
Lieutenant-Commanders	34
Lieutenants	10
Junior Lieutenants	17
Total	81

This was totally inadequate for the work for which the Chief Constructor became responsible. By law two construction officers are allowed for every 1,000 men in the Navy. With a war strength of 187,500, this gave 375 officers to the Construction Corps, and with the present peace strength of 137,500 there should be 275 construction officers. The Corps was brought up to a war footing by appointments of officers of the United States Naval Reserve Force as Naval Reserve Constructors, of Chief Carpenters and Carpenters of the Navy, and of a number of suitably qualified civilians who took a short intensive course at the Institute of Technology.

At the time the Armistice was signed the Corps, so enlarged, was distributed as follows :—

—	Admirals.	Captains.	Commanders.	Lt.-Commanders.	Lieutenants.	Junior Lieutenants.	Ensigns.
Bureau of Construction and Repair	2	7	8	2	2	—	—
Navy yards in the United States	—	4	15	18	94	11	11
Navy yards outside the United States, including Canal Zone	—	—	1	1	7	—	1
Superintending construction and inspecting materialin private yards and aircraft factories ..	—	5	5	4	31	12	7
On staff of commandants of Naval Districts	..	1	—	—	8	2	1
At training stations, on salvage work, and miscellaneous	—	—	—	3	6	2	—
At United States bases in Europe	—	1	2	1	3	1	—
As fleet constructors, &c., at sea	—	—	1	—	5	—	—
Total	2	18	32	29	156	28	20

In addition to the above, one commander and one ensign have been lent (the former as Vice-President) to the Emergency Fleet Corporation.

The Work of the Corps during the War.

The magnitude of this work can be judged from the following statements of the additions to the strength of the United States Navy after the American declaration of war and of the naval construction in hand at the time the Armistice was signed :—

1. *Additions to the United States Navy between April 6, 1917, and November 11, 1918.*

Battleships	2
Destroyers	44
Submarines	36
Mine-sweepers	16
Patrol vessels (200 ft.)	3
Submarine chasers (110 ft.)	308*
Fleet auxiliaries	2
Aircraft lighter than air	367
Aircraft heavier than air	2,563

*Also 100 built for French Navy.

In addition to the above, 36 ex-German vessels were converted to the service of the United States Navy and

744 privately-owned vessels were fitted out as mine-layers, mine-sweepers, supply ships, patrol boats, &c.

2. *United States War Vessels under Construction or Designed on November* 11, 1918.

	Under construction.	Designed but not commenced.
Battleships ...	7	6
Battle cruisers ...	—	6
Scout cruisers ...	5	5
Destroyers	227	21
Submarines ...	71	25
Mine-sweepers ...	38	—
Patrol vessels (200 ft.)	57	52*
Submarine chasers (110ft.)	39	—
Fleet auxiliaries ...	70	8
Aircraft lighter than air	44	284
Aircraft heavier than air	666	1,367

* Twelve for Italy.

In conclusion, the author desires to express his thanks to Admiral D. W. Taylor, Chief of the Bureau of Construction and Repair, for permission to publish the information given in this paper.

ALL-METAL PASSENGER RAILWAY CARS.*

(1) *The Electrical and Mechanical Equipment on the All-Metal Cars of the Manchester-Bury Electrical Section, Lancashire and Yorkshire Railway.*

By GEORGE HUGHES, M.Inst.C.E.

The author confines the scope of this paper to the electrical and mechanical equipment of the motor cars employed on the Manchester to Bury section of the Lancashire and Yorkshire Railway, based upon existing facts without serious embellishment owing to the reduction of staff and personal time due to the war.

When new motive power is required, the railway engineer has to consider the following points:—Geographical position, gradients, junctions, density of traffic, difficulties of operation, possible range of user, and future developments.

The paper is arranged in the order as appertains in the passage of current:—

A shoe collects current from a side-contact live rail, the shoe pressure being 25 lb. This shoe, fixed to the bogie, is connected to the trolley cables, from which connections are taken through the various parts of the equipment to the motors. A connection is taken to a rotary transformer, which supplies low-tension 100-volt current for operating the control equipment.

The trolley cables have been housed in Jarrah wood, as this material has been found the most satisfactory.

The electrical connecting of coaches is accomplished by "plug and socket" type couplers; the high tension (1,200-volt) is connected to the trolly cable, and the low tension (100-volt) to the rotary transformer; also a control coupler is connected to the multicore cable for the contactors.

The 1,200-volt portion of the equipment is placed in a high-tension compartment, completely isolated from the remainder of the car, the door of this compartment being interlocked with the main switch, which is of the single-blade type.

The rotary transformer is a 10-k.w. machine; it has two windings on the armature, and is operated on the high-tension side by an automatic control-switch which is necessary owing to the gaps in the live rail.

The electrical control equipment is of the shunt multiple-unit type, arranged for automatic or manual operation in the forward position, and manual only in the reverse. Field control is also provided for.

The automatic control is operated by means of relays governed by the main motor current. Succeeding contactors cannot operate until the motor current has fallen to a predetermined value, and the sequence of operation is controlled by electrical interlocks.

The controller has nine positions of the handle, the last being for supplementary field control, and there are four positions of the reversing handle.

The main circuit-breaker is of the magnetic shield type, and can be tripped or re-set from the motorman's compartment.

The contactors are made up in two groups, one group at each end of the car, and controlling two motors. Each single contactor is fitted with a magnetic blow-out coil and two arcing horns protected by soapstone shields.

The motor cut-out is manually operated, and when in the normal position two motors are in circuit; if moved in either direction one or other of the motors is cut out.

Each reverser controls two motors, and is solenoid operated from the master controller.

In the motor-bogie the best locomotive practice has been adopted, and the design is the outcome of the development of the built-up frame bogie. The gear wheels are pressed on to the axle and bolted to the wheel centre. They are of mild steel, with involute teeth, No. 2 diametral pitch, and the load is taken uniformly on two teeth throughout the arc or action. The road wheels are of the standard locomotive-spoked type, and the tyres are made of Siemens-Martin steel of locomotive pattern but 5 in. wide, and are shrunk on to the wheel centres. The wheel centres are steel castings made by the Tropenas process. The bolster is of the box-girder form, with a lateral movement of 1¼ in. each way. A double-brake block arrangement is fitted, and the average life of a brake block is about 5,700 stops, excluding signal checks and coasting on down grades. Each bogie is fitted with two motors geared to the axle through spur gearing, the ratio being 2·36 to 1·00.

Nose suspension of the motors is adopted, half the weight being spring-borne, and the other half resting directly on to the axle.

The motors are 200 h.p., and have been designed on the experience gained on the Liverpool and Southport line. Solid field frames have been used, also increased ventilation provided for, and interpoles fitted. The field and interpole coils are vacuum impregnated and enclosed in brass cases. The temperature rise of these motors is 55 deg. C. after one hour's run at full load. The quality of steel for field frames was investigated, and it was proved that a mechanically stronger casting could be manufactured with only a very slight reduction in permeability, and a B.H. curve is shown of two different qualities of steel, also a characteristic curve of the motor.

The vacuum-brake equipment is of the simplest possible form, and its leading features are the installation of a pump capable of releasing the brake in 12 sec., and a brake valve which admits air to the train pipe, and also starts and stops the pumps. A separate vacuum reservoir is provided for operating the horn in case the current is cut off for a short time. In the design of the brake-valve the "dead-man's" handle is incorporated, which applies the brakes and cuts off current to the main motors.

The vacuum-pump has forced lubrication. Inlet and outlet valves are fitted in the cylinder heads, and these can be easily and quickly removed. The motors of 5 h.p., for driving the pumps are series wound, and running at 1,000 r.p.m. on a 100-volt circuit. This pump is operated through a switch in the brake-valve and an automatic regulator.

Below the brake-valve is a tripping-switch, which brakes the master-controller circuit when the "dead-man's handle" comes into operation, or when the motorman uses a special key for converting the brake-valve into an ordinary van valve.

The high-tension wiring is kept separate from the low tension.

Bell code signals between guard and motorman are supplied with current from a small battery of accumulators; the latter are also used for emergency lighting.

The lighting of the cars is taken from the 100-volt circuit, and the heating from the 1,200-volt circuit.

The different portions of equipment receive an examination and attention at the end of periods varying from three days for vital parts to twelve months for general overhaul, and the author considers that this periodical examination has largely contributed to the efficient service of the electrified lines. Comparisons are given of the average faults on trains on the Manchester to Bury, and the Liverpool to Southport sections.

(2) *All-Metal Passenger Cars for British Railways.*

By FRANCIS EDWARD GOBEY, O.B.E., Assoc.M.Inst.C.E.

In Great Britain there are 52,250 passenger carriages for use on the railways.

These passenger cars have mainly timber structures, the simplicity of manufacture and quanity of timber available being no doubt the principal reasons for this policy. From a study of the present conditions the development to all-metal vehicles appears the natural evolution.

This paper is intended to indicate the reasons which make a departure from timber to metal construction necessary; to illustrate the existing cars in use in Great Britain and in the United States, a country which is nearer parallel than that of a tropical climate, and where metal construction is the standard practice; and, finally, to suggest the broad principles for the design and construction of all-metal passenger cars to be used for main line and suburban services on the railways of Great Britain. Cars for underground railways are not included.

Underframes and bogies for passenger cars have been built of metal for many years in Great Britain, but the entire adoption of metal instead of timber for the body structure has not yet developed in this country.

Consideration is only given to what are known as third-class cars, as the principles set out for this type of car will apply equally to other classes of cars when required to be built.

Certain equipment in a passenger car which is common to a metal or a timber vehicle, such as bogies and buffing and drawgear, are only referred to so far as they illustrate progress in design.

The use of metal in existing British cars is first briefly described, and Appendix I sets out the number of passenger cars with bodies and underframes built of timber and metal; this is followed by statements of the present and anticipated timber shortage and the position of metal supplies.

The prominence given to the subject of telescoping and fire when accidents have occurred to passenger trains in recent years is dealt with by a citation of some of the recommendations made in Board of Trade reports and by showing that metal construction would more completely protect passenger rolling-stock and secure the greatest safety to the travelling public.

The experience of railroads in the United States, where 17,601 steel passenger cars are in use, is fully illustrated with reasons for the policy adopted, descriptions of typical steel cars and data showing the progress made.

The principal feature in the paper is a full description of the all-metal electric cars of the Lancashire and Yorkshire Railway, which are the only railway passenger cars constructed entirely of metal in Great Britain. The details of design are recorded for the first time, with tables showing the relation of timber and metal constructed cars for weight and cost, and also the maintenance experience during a period of two and-half years. The author draws attention to some special features of metal vehicles after briefly touching on the tendency to uniformity of stock if metal construction is adopted, discussing the general design of cars and efficiency of passenger accommodation for main-line and suburban services in Great Britain.

An all-metal open car is advocated of an economic width and length to give the greatest comfort to passengers and the best results in efficiency; comparisons are made of typical designs with the present types of cars operating on British and American railways in tables and diagrams, and the paper concludes by referring to some of the interesting features affecting the future of all-metal passenger cars on the railways of Great Britain.

* Abstracts of two papers read before the Institution of Civil Engineers on Tuesday, April 8, 1919.

RUSSIAN INDUSTRY UNDER THE NEW RULE.

ONE of the Russian delegates at the International Socialist Congress at Berne, Gavronski by name, a revolutionary socialist, has given interesting information on the disastrous effect of Bolshevism upon the industries of Russia.

Considering the thousands of decrees which the Bolshevist Government has issued, one would imagine that the aim was the establishment of a Socialistic State in Russia, but as a matter of fact the outcome is a complete decay of national economy, industry, &c.

When the Bolshevists started "organising industry on a new basis," they followed their usual tactics. They introduced "workmen's control," which means that the different undertakings were placed under the control of factory committees, consisting of workmen and functionaries. Now, after the lapse of a year, they are compelled to admit that the workmen's control has completely failed. The workmen's control has degenerated into ownership of the industrial undertakings, the original owners having been eliminated. But this change has most assuredly not had for effect to bring about any improvement in production for the benefit of the State and the community. In the metal industry, for instance, the wages of the workmen and the pay of the functionaries last summer amounted to 105 per cent. of the gross value of the production, and it has been ascertained for a whole series of factories, that the aggregate value of the goods produced did not exceed 70 per cent. of the working expenses. In this connection it is significant to note that the well-known Putiloff works, in the course of a comparatively short period, received 96,000,000 roubles in State subsidy; of this sum, 66,000,000 roubles went to workmen's wages, whilst the aggregate value of the production only amounted to 15,000,000 roubles.

Industry in the hands of the Soviet Republic exists—if it can be said to exist at all—solely by the aid of State subsidies, whilst the value of the entire production hardly amounts, as a rule, to 50 per cent. of these subsidies. Under these circumstances it goes without saying that the bankruptcy of the State cannot possibly be avoided, or, more correctly, it has already commenced. This also appears from the fact that the half-yearly budget, which the Commissary of Finance, Guloffski, has drawn up, amounts to the substantial figure of 80,000,000,000 roubles, and this with a literally complete absence of revenue. The only sources of income of the Soviet Government are from the printing machines. No wonder, that the Russian rouble has already lost 95 per cent. of its value.

The State and the great bulk of the people are suffering immense losses, and only a comparatively small number of workmen derive any advantage from the manner in which the Soviet Republic manages industry. This advantage, to a limited number of men, consists partly in the unproportionately high wages and partly in the manner in which the produced goods are distributed. Thus each workman of the Prokhoroff works, at Moscow, received 30 m. of cloth for himself and for each member of his family every month during the summer of 1918. Under those circumstances, it is not to be wondered at that a number of peasants and soldiers demanded, backing up their demands with violence, to be engaged at the works, although they had no experience whatever in textile work; all they wanted was their share of the high wages and the profuse cloth allowance. This purely and simply means downright robbery and the plunder of the factories.

The Russian working classes have thus become the owners of the industrial undertakings. But the undertakings are coming to grief entirely, unemployment is on the increase, famine in the great towns is growing more and more serious, and the workmen themselves decrease in numbers and tend to resort to the villages. Only isolated circles and parasites are continuing to derive any benefit from the general dissolution.

As little as the ownership of the factories has benefited the workmen as a whole, so little has the ownership of the land proved an advantage to the peasants. In some parts of Russia, the peasants die from starvation, and in districts where there is grain, the villages are simply smothered with paper money, which has no real value, and in exchange for which the peasants cannot buy anything. The whole mass of the agricultural classes is becoming gradually more impoverished. It is only a few speculators and the agents of the Bolshevist Government who are enriching themselves.

GERMAN AIR TRAFFIC.—A regular air service has now been commenced between Berlin and Munich, by way of Augsburg, the aeroplanes used being small machines only capable of carrying one or two passengers and some mails. The fare charged is 2½ marks per kilometre, which makes the cost of the trip from Berlin to Munich 1,260 marks.

THE WATSON-BOOTH ACOUSTICAL THERMOMETER.

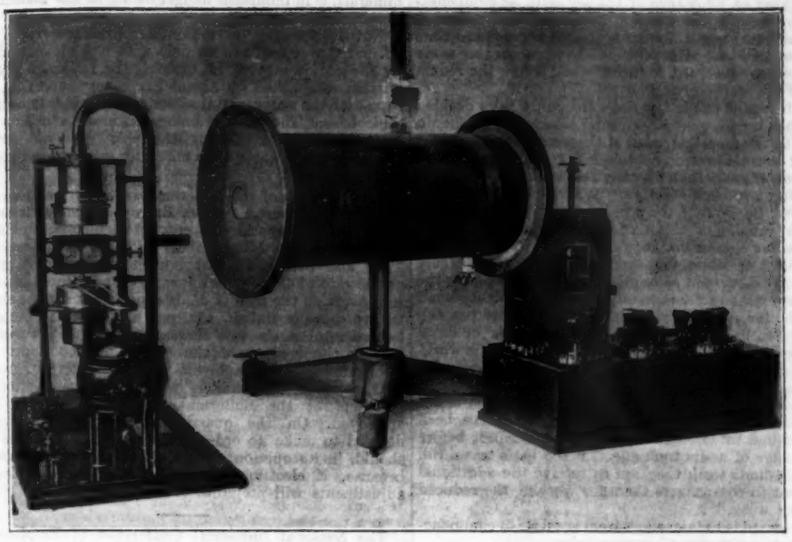


FIG. 1.

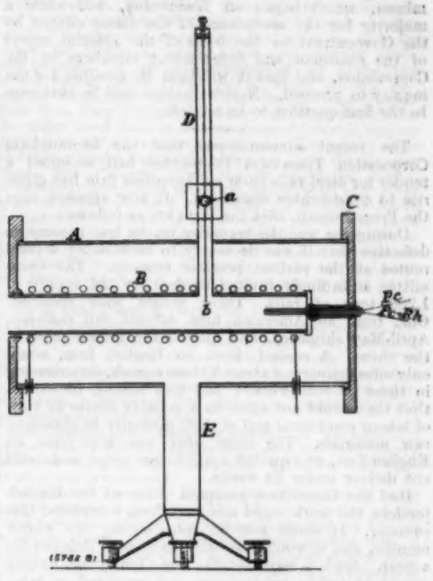


FIG. 2.

MORE than two years ago we illustrated, on pages 380 to 382 of our issue of October 20, 1916, the arrangements by means of which Professor T. R. Watson, of the University of Illinois, had improved the acoustics of the auditorium of his university, correcting the bad echoes and prolonged reverberation. This was not his first successful work in architectural acoustics; he had previously made the large armoury of Illinois, a building 400 ft. by 212 ft., 93 ft. high, resembling our St. Pancras station, which had been built as a drill hall, fit also for public speaking, and he had been able to effect these improvements by the aid of various devices of his own design for measuring and adjusting the intensity, reflection and absorption of sound. Thus he used megaphones for directing sound waves towards various parts of the building, and he determined the intensity of the reflected cone of waves with the help of a telephone receiver and a hot-wire galvanometer. We have mentioned some of these instruments on other occasions.

The acoustical thermometer which we illustrate on this page by Figs. 1 and 2 is, so far at any rate, not a thermometer likely to replace mercury bulbs or gas or electric thermometers, but an apparatus designed for the purpose of testing the formula accepted for the variation of the rate of propagation of sound through air with the temperature of the air or other gas. The arrangement is due to Professor Watson and Mr. H. T. Booth. The formula for the variation of the sound velocity with temperature is:

$$V_t = V_0 \sqrt{1 + a\,t} = V_0 \sqrt{\theta/273},$$

where the V indicates the velocity at temperatures of 0 deg. and t deg. C., a is a coefficient, and θ is the absolute temperature of the air. Combining these quantities with N, the pitch of the sound of wave-length λ under examination, such that $V = N\lambda$, the formula may be written $N^2 = V_0^2\,\theta/273\,\lambda^2 =$ constant $\times\,\theta$, if λ be constant. Thus when λ is constant, N^2 should vary as θ. The determination of the velocity of sound at high temperatures involves difficulties; very little has been done in that line, and any instruments enabling the formula to be tested are hence of considerable theoretical interest; the practical interest may later become apparent.

The essential part of the apparatus is the cylindrical resonator of constant length which can be electrically heated, and which is shown in the centre of Fig. 1 and in longitudinal section in Fig. 2. To the left, in Fig. 1, is the Helmholtz siren, which is worked by an electric motor to produce a sound, the pitch of which is read off on the counter shown in the photograph. The siren is placed in front of the resonator to allow the latter to respond to the sound produced. The resonator consists of two concentric metal tubes A and B so connected and closed by discs C, as indicated in Fig. 2, that the central tube B can receive the sound waves from the siren; a heating coil encircles the cylinder B, and the whole is mounted on the stand E. Acoustically, the resonator is of the Rayleigh type. A flat circular disc b is so suspended by a thread passing down the column D that b is at a loop of the sound wave generated, at one-third of the length of the cylinder counted from its closed end; the resonator tube then will respond to its first overtone, the length l of the tube representing $\frac{3}{2}\lambda$. When in that position and adjusted to form an angle of 45 deg. with the longitudinal axis of the cylinder, the disc b is rotated by siren sounds whose pitches are the same or approximately the same as that of the resonator. The experiments are conducted in the following way: The resonator is heated up until it has attained the desired constant temperature, which is determined by means of the thermocouple shown, this being formed by wires of platinum and of platinum-rhodium. The siren is set in motion, and the pitch is raised until the resonator disc b—or rather the second similar disc a fixed higher up the thread, outside the cylinder—shows a maximum deflection; the pitch of that note is assumed to be equal to the pitch of the resonator. The experiment is then repeated at a higher temperature. The plotted observations marked a linear relation between N^2 and θ in accordance with theory; but the agreement was not perfect. The experiments were hence repeated with other instruments, and the arrangements were modified. The final result deduced was that the proportionality between the square of the pitch and the absolute temperature held for temperatures up to 400 deg. C., which, we believe, is a very much higher temperature than had been attained in previous experimental verifications. Above 400 deg., however, the disturbances due to convection currents and to other sources made the readings too uncertain. Professor Watson therefore plans further experiments, in which use is to be made of two resonator tubes and the suspended system is to be modified.

STANDARDISATION OF AIRCRAFT MATERIALS AND PARTS.

IT will be recalled that during the past year and a half the British Engineering Standards Association has been responsible for the preparation of all specifications for aircraft materials on behalf of the Department of Aircraft Production. During this period some 70 British standard specifications for aircraft materials were issued, and a further 60 were practically complete at the time of the cessation of hostilities. These specifications were distributed to the makers by the department, as the whole of the aircraft production of this country was under its control. These conditions are now changing, and at the request of the Air Ministry and the Department of Aircraft Production, and with the cordial support of the Society of British Aircraft Constructors and the Steel Research Committee and other associations, the British Engineering Standards Association have been requested to continue the preparation of specifications for aircraft materials and parts as well as undertake their distribution, together with the issue of manufacturing instructions and notes on testing procedure which were formerly prepared and issued by the Technical and Inspection Departments of the Department of Aircraft Production. This request was considered at a recent meeting of the Sectional Aircraft Committee of the British Engineering Standards Association, and, with the approval of the Main Standards Committee, the association has undertaken this additional responsibility as from March 31, 1919.

It is proposed to reorganise on a peace basis the various sub-committees concerned with the preparation of these specifications. These sub-committees, when reorganised, will undertake the revision of the specification for peace purposes. In the meantime, the whole of the 200 specifications in use by the Department of Aircraft Production have for immediate purposes been adopted as interim British standards. During the war, a large number of firms were engaged in the manufacture of aircraft materials and parts, but are now returning to their former occupations, and arrangements for the distribution of these specifications which have been in force during the past year will not apply in the future.

It is not proposed to circulate copies of all specifications to every maker concerned with the production of aircraft materials, but to ask the makers to indicate which they are interested in. A complete list of the specifications now available, will shortly be circulated to the 2,000 contractors on the former despatching list with the request that they indicate the specifications they desire copies of. It is recommended that a small charge should be made per copy to cover the cost of printing. The charge will probably be 1½d. per copy for those specifications issued in leaflet form, and 1s. for those specifications issued in the ordinary British standard octavo book form. This arrangement is, however, provisional.

There can be little doubt that the preparation of specifications by the British Engineering Standards Association in the manner adopted whereby manufacturers and users, together with technical officers of the Government Departments interested, as well as experts from research laboratories and colleges and consultants, co-operate in their production, coupled with the principle of not issuing a British standard specification until practical agreement has been reached, is very sound, and a wide use of these specifications for all aircraft production may confidently be expected. It is interesting to note that specifications dealing with materials which formerly were perhaps not considered as being of an engineering nature, have been prepared, such as chemicals, textiles, paints and varnishes.

THE BERLIN ELECTRIC LIGHT AND POWER COMPANY.—This concern, which has a capital of 30,000,000 marks, is already feeling the effect of the altered state of affairs, inasmuch as the year 1917–18 closes with a loss of 78,833 marks. The net profits for the previous year were 1,644,611 marks, at about which figure they have remained during the war. Although for the year 1912–13 the profit made was 2,593,475 marks. Last year 1,800,000 marks had to be written off on foreign holdings, principally Russian, the Russian Government having appropriated the company's concerns in that country. Full reports relating to the works in overseas countries had not come to hand. The Compania Pevillana de Electricidad is constructing an additional hydro-electric power station at Guardioro, the share capital being increased from 4,000,000 pesetas to 20,000,000 pesetas for this purpose. The Societa Elettrica Riviera di Ponente has also increased its capital, to 110,000,000 h. in order to extend its area and acquire the majority of the shares in the Officine Elettriche Genovesi, which supplies Genoa and its environs with electric energy. In addition to its share capital of 30,000,000 marks the Berlin Electric Light and Power Company has debentures issued for 36,140,000 marks.

INDUSTRIAL NOTES.

THE general expectation is that the ballot of the miners, which began on Wednesday, will show a majority for the acceptance of the terms offered by the Government on the basis of the interim report of the chairman and independent members of the Commission, and that it will thus be possible for the inquiry to proceed. Nationalisation will in that case be the first question to be settled.

The recent announcement that the Birmingham Corporation Tramways Committee had accepted a tender for steel rails from an American firm has given rise to considerable discussion. It now appears, says the Press Bureau, that the facts are as follows:—

During the war the tramway tracks had become so defective that it was necessary to reconstruct several routes at the earliest possible moment. The Committee accordingly invited tenders for the supply of 1,200 tons of rails. Three replies were received. One, from an American firm, offered full delivery, April-May shipment, and quoted the lowest price of the three. A second, from an English firm, could only offer delivery of about 50 tons a week, commencing in three or four weeks; the firm stated, moreover, that they could not agree to a penalty clause in view of labour conditions and of their difficulty in obtaining raw materials. The third offer was also from an English firm, who quoted a still higher price, and could not deliver under 20 weeks.

Had the Committee accepted either of the English tenders, the work could not have been completed this summer. It could not be done during the winter months, and it would therefore have been delayed for a year. Such a responsibility the Committee, having regard to public safety, were not prepared to take. They were therefore obliged, adds the Press Bureau, to accept the American tender.

Mr. Robert Young, M.P., of the Amalgamated Society of Engineers, addressed the Yorkshire Centre of the Industrial League at the Hotel Metropole, Leeds, on Wednesday, the 2nd inst., on "Workshop Committees as a Prevention of Industrial Unrest."

In the course of his speech, Mr. Young said the problems surrounding us were just as great in relation to reconstruction as they were during the war, and it behoved all of us to see that in the days to come we should do nothing which would keep our country from returning to the prosperity among nations which it enjoyed before the war. The prosperity of past years would not be guaranteed to us unless workmen looked at industrial problems from a new standpoint. They must realise as never before that they were partners with the employers in creating and maintaining the wealth of the country. The time had gone by when the workman should be regarded as a mere cog in the wheel; on the other hand, the workman must realise that employers had their difficulties. He held that British working men and employers were capable of maintaining the standard of prosperity, even if workers were better paid and had shorter hours, if these were not too disproportionate to the hours and wages observed in other countries. Mr. Young further stated that he did not think we were likely to make progress if we adopted the old methods of settling disputes. Negotiations should always precede any stoppage. Many matters came before national executives of trades unions which, if common sense were applied, could have been settled inside the workshop, assuming the machinery had existed. New methods had to be devised for bringing employers and employed together—not merely trade union representatives, but the workers in the workshops meeting the management or the employers in a particular establishment. Whatever the talk about Whitley Councils, he thought such workshop committees would enable them to smooth out many difficulties. Workmen should have greater responsibility and interest in settling the conditions under which they worked. He thought workshop rules could be agreed upon, working hours settled, piecework wages and holidays arranged. Even in the matter of workshop discipline employers and workmen had many matters to bring to each other's notice.

Dealing more particularly with foreign competition, Mr. Young stated he was certain that the men who were saying, "Do as little as you can and you will create more work," were altogether wrong. Not one of them, if he were in business on his own account, would act on such a principle. On the contrary, he would say that it was his duty and interest to produce as much as he could, and by so doing he would not only lower the cost of his commodity and create a larger demand for it, but would make more work for other people as well as for himself.

The shipbuilding arbitration award was issued last week. The parties in the case were the Shipbuilding Employers' Federation, the Boilermakers' and Iron and Steel Shipbuilders' Society, the Ship Constructors' and Shipwrights' Association, and the Associated Blacksmiths' and Ironworkers' Society.

The chief claims were that all pieceworkers should be granted an allowance of 12½ per cent. as compensation for the reduced working week, and that workmen paid at hourly or daily rates above the standard time rates should be paid for a 47-hour week the same rate as they received for a full week before the reduction of the working week.

With regard to pieceworkers the court have decided that in a broad, general sense no loss would or should result to the men by reason of the number of the hours of the normal working week being reduced from 54 or 53 to 47, and that no case has been made out for awarding any compensation. Where such loss occurs, however, the court have decided that the matter shall be the subject of negotiations between the parties, and, failing agreement, shall be referred to the Arbitration Court or other independent tribunal. In the case of lieu workers paid at hourly or daily rates above the standard time rates, the court decided that they shall be paid for a 47-hour week the same rates per full week or ratio for the fewer number of hours' or days' work as they received before the reduction of the working week, except as regards lieu workers, whose rates are based on their additional piecework earnings, in which case the court decided that their claim is not established. In any cases in which men have been paid at lieu rates based on piecework earnings before the change of hours took effect, if the basis was a full 53 or 54-hour week they are to receive the additional payment to compensate them for working the reduced working week.

The award is to take effect from the date of commencing work under the 47-hour scheme.

The Government have approved proposals for the setting up of a series of joint bodies for the Civil Service, from a National Council down to sectional committees, for the consideration of conditions of service, and other matters. A conference of departmental officials and representatives of the workers referred the scheme to a national joint committee for consideration.

According to the report of the accountants to the Midland Iron and Steel Wages Board, the output of iron by 17 selected firms during January and February was 22,325 tons, an increase of 216 tons over the previous two months' output. The average net selling price was 17*l.* 11*s.* 11*d.*, or 1*l.* 0*s.* 5*d.* per ton more than in November and December. Puddling and other forge and mill wages in the Midlands during April and May will therefore be advanced by 10 per cent.

The first interim report (dated the 3rd inst.) by the Committee appointed at the Conference of Northern London Manufacturers and Labour Representatives held at the Royal Automobile Club on February 9, has now been issued. The Conference was convened by the North-Eastern Manufacturers' Association, Station Chambers, Bruce Grove, Tottenham, N.17.

From the report in question we gather the following eight basic principles, on which unanimous agreement was arrived at subsequently by the Committee:—(1) Industry rightly belongs neither to the capitalists nor to Labour. It is the organisation by which are produced the commodities necessary for the welfare of the community of which they form the industrial constituents, and in whose service it should be carried on by them in trust. (2) Capital and Labour are morally and economically partners in industry, and by reason of their different functions no distinctions can exist in the relative importance of the services rendered by each. (3) Neither the control of industry nor its benefits can be rightfully claimed or advantageously possessed either by owners of capital invested or labour engaged to the exclusion of the other. (4) The function of capital is that it be applied productively and sufficiently for the general good. (5) The function of labour is to produce to its full capacity. (6) The "standard of living," representing as it does the division of the commodities produced by the community amongst its members, is directly proportional to production, provided that the said division is equitable, having regard to the services rendered. (7) The rewards rightly due for services rendered are as follows:—First, to Labour a reasonable living wage; secondly, to Capital in respect of money secured by assets a reasonable fixed rate of interest, sufficient to secure its employment; thirdly, to Labour 50 per cent. of the net divisible profits; to Capital, 50 per cent. of the net divisible profits. (8) The term "labour" comprises workers both by hand and brain, and includes management.

The report further contains a number of suggestions and recommendations of great interest to both employers and employed.

A correspondent, writing to *The Times* from Dudley, states that the Black Country coalfield, which extends for over 65 square miles and, according to experts, contains considerably over 100,000,000 tons of ungotten minerals, is in imminent danger owing to the alarming rise in the water.

Notwithstanding a maximum drainage rate of 9*d.* per ton of coal raised, paid with a few exceptions by the coalowners of the district, the Drainage Commission established by Act of Parliament is unable to cope with the water, and that body is in serious financial difficulties. The work is being continued at a loss of 1,000*l.* per week. During the past year no fewer than 52 tons of water were raised for every ton of coal.

The members of the Boilermakers' Society employed by Messrs. Vickers, Limited, Barrow, recently claimed that all beginners and improvers in electric welding should be *bona fide* members of their organisation. They also demanded that beginners should be paid at the rate of 4*l.* per week for the first six months and improvers at the rate of 4*l.* 10*s.* per week for the first twelve months and 4*l.* 15*s.* per week for the second twelve months, the rate thereafter to be 5*l.* per week. During the hearing of the claims by the Court of Arbitration the employers' representative agreed that, so far as boilermakers' work was concerned, only members of the Boilermakers' Society should be employed. On the question of wages the Court decided to make no order. The matter is one which should, in its opinion, be settled on a national basis, because, if electric welding becomes general, local adjustments will prejudice the larger issue.

The National Industrial Conference of Employers of Workmen, representing almost all the great industries of the country, met again in London last Friday, the 4th inst., as announced on page 317 *ante*. The meeting had before it, at the morning sitting, a detailed report stating the recommendations of the Joint Provisional Committee, which may be briefly summarised as follows:—

A legalised maximum normal working week of 48 hours in all industries, with such exceptions as are unavoidable.

Legalised minimum rate of wages to be of universal application, the commission to report in three months as to what these minimum rates should be.

Discouragement of systematic overtime.

Trade conferences to consider how war advances and bonuses should be dealt with.

A full and frank acceptance in trade negotiations of employers' organisations and trade unions.

Organised short time, and regulation of Government orders and pushing forward of Government housing schemes to prevent unemployment.

An adequate provision for the maintenance of the unemployed and under-employed.

Child labour age to be raised and more generous provision for sickness and infirmity benefit and old-age pensions.

Inquiry to be made of the effect on the labour market of the employment of married women and widows.

The establishment of a permanent national industrial council of employers and workers to advise the Government on industrial questions.

In the course of the afternoon sitting, Mr. Arthur Henderson, Chairman of the Trade Union side of the Joint Committee, moved the following resolution, which was carried:—

"That this joint National Industrial Conference, representing the employers and the trade unions, welcomes the report of the Provisional Joint Committee and agrees to submit it for the acceptance of its constituent organisations immediately the Government officially declare their readiness to proceed at once with the legislative and other steps necessary to carry the report into effect.

"That the Provisional Joint Committee remain in being until the National Industrial Council and the Standing Committee have been brought into operation."

Sir Robert Horne, Minister of Labour, after declaring the resolution carried, said he was greatly pleased at the prospects of a settled industry throughout the country.

DISCONTINUANCE OF IRON AND STEEL SUBSIDIES.—The Ministry of Munitions gives notice that all subsidies in connection with the manufacture of iron and steel, including those on iron ore, coke and pig-iron, will be withdrawn on April 30, 1919. The control of prices and allocation of all descriptions of metallurgical coke, iron and steel scrap, cinder and scale, iron ore, pig-iron, manufactured iron and steel and tin plates, will cease as at that date. Subject to the provisions of existing contracts, and to any regulations in force from time to time with regard to export, makers and others are free to make their own terms and arrangements in respect of delivery of any of these materials for home or export on and after May 1, 1919.

THE DEVELOPMENT OF AIRSHIP CONSTRUCTION.*

By C. I. R. Campbell, R.C.N.C., Member.

In view of the growing importance of airships, it may be expected that many papers concerning them will appear in future Transactions of this Institution. The present paper is therefore intended to be introductory in character, the subject being treated in a very general manner, so as to indicate the stage of development now attained by airships, and the manner in which some of the problems of design are dealt with. It is hoped, also, to bring out the fact that airship design is very closely allied to the work normally performed by naval architects, and should, consequently, not be allowed to drift into the hands of those whose training has not fitted them to deal with the problems that are involved. Limitations of time and space have prevented reference to many matters, such as mooring out, handling arrangements on the landing ground, &c., which are of vital importance to successful development. Much information regarding airship performances has recently been published and has therefore been omitted here.

Introduction.—In the present paper, the term "gas" will be used to denote the impure hydrogen used in airship envelopes and gasbags. The impurities in the hydrogen consist chiefly of the constituents of air, and the assumption made is that they have, in the aggregate, the same weight per cubic foot as air; thus, when it is said that the purity of gas in an envelope is, say, 95 per cent., it is assumed that the total buoyancy in air of the gas is the same as that of pure hydrogen at the same temperature and pressure, but having a volume only 95 per cent. of that of the gas. If, in such a case, V denotes the total volume of the gas, W the weight per unit volume of the surrounding atmosphere, w the weight per unit volume of hydrogen, then the buoyancy of "total lift" is $\cdot 95\ V \times (W - w)$. In British practice, it is the custom for design purposes to assume that $(W - w)$ equals ·068 lb. per cubic foot, and hence that the gas has a lift of 68 lb. per 1,000 cub. ft. at sea-level. The practice in this matter varies in different countries, and this is the cause of much confusion when comparing the performances of foreign and British airships.

The air density decreases as altitude increases, and the lift of an airship decreases accordingly. Fig. 1, annexed, shows, in the form of a curve, the average lift per unit volume of gas at various altitudes as a percentage of the lift at ground-level. The curve is based upon data as to average atmospheric temperature and pressure, supplied by Sir Napier Shaw, and applies especially to South-Eastern England.

As an airship rises, the external pressure falls, and the gas in her envelope or gasbags tends to expand. In the case of a rigid airship, where the gas is contained in internal gasbags which contribute nothing to the strength or external form of the ship, the expansion of gas can be provided for by starting from ground-level with the bags only partially inflated. Then, if it is desired to reach a height of, say, 9,000 ft., it would be economical to start with the bags only 75 per cent. full, so that on reaching the height mentioned the bags would be just full. Any further rise would then involve further expansion of the gas, causing a loss of gas through the automatic relief valves. The height at which the gasbags are just full to blowing-off pressure of the valves, is called the "pressure height." As the total lift of a definite mass of gas is the same at all altitudes provided that its temperature and pressure are always those of the surrounding air, apart from the effect of humidity, it follows that the total lift of an airship is nearly the same at all altitudes provided that no gas is lost. Hence a very small vertical force is sufficient to cause a rigid airship to rise or fall between sea-level and the pressure height, and she can be navigated between these limits by means of her elevators alone without loss of ballast.

In non-rigid airships, the gas is contained in an envelope which forms the body of the airship. The shape and rigidity of the envelope must be maintained under all conditions of flight, and as these qualities are due solely to the internal pressure of the gas in the envelope, it is necessary to make provision for the expansion and contraction of volume to take place with variation of altitude, without alteration of the gas pressure as measured by gauge.

For this purpose large fabric air chambers called "ballonets" are fitted inside the lower part of the envelope, and are freely connected to a source of air compressed to the pressure which it is desired to maintain in the envelope. During flight, the ballonets are always in a state of greater or less inflation, *i.e.*, they are never either full or empty, consequently the pressure of the air within them must always equal the pressure of the gas without, and by controlling the former we are able to control the latter.

When the airship rises, the gas in the envelope expands and forces some of the air out of the ballonets until equilibrium is restored. When the airship descends, the reverse process takes place.

It is clear that the capacity of the ballonets must be sufficient to take up the full range of contraction of the gas as the airship descends from the maximum altitude to sea-level. In many airships their capacity is about 30 per cent. of that of the envelope.

The source of compressed air to the ballonets may be an ordinary blower, but when the airship is in flight, the most convenient system is to connect them by means of suitable air ducts to an air scoop somewhat on the principle of the ordinary ship's cowl, having an open mouth just behind the propeller, so as to take advantage of the kinetic head of the slip stream from the latter.

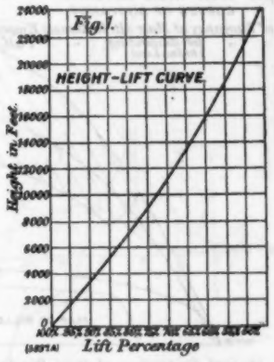
In some semi-rigid types, where a very low envelope pressure is used, the ballonets are connected by a duct to a valve in the nose of the envelope, fitted with suitable shutters. When the ship is proceeding at sufficiently high speed, the kinetic head at this opening produces the required pressure. The rate of supply of air to the ballonets for which provision must be made depends upon the desired maximum rate of descent of the airship, *i.e.*, it must be sufficient to deal with the maximum rate of contraction of the gas in the envelope which is liable to occur in service.

Airship Types.—In airships, as in other ships, a dominating requirement in design is the provision of the longitudinal strength necessary to withstand the longitudinal shearing forces and bending moments resulting from the loading and from the varying pressures of the surrounding medium. The different means adopted to meet this requirement divide airships into three main types, viz.: non-rigids, semi-rigids, and rigids.

Non-Rigid Airships.

This type includes all those airships in which the form of the envelope is maintained solely by the internal gas pressures. The principal varieties are:—

(*a*) Those having an envelope of nearly circular cross-section, the car suspensions being connected to fabric patches or long strips stuck, or sewn and stuck, on to the outside of the envelope. In this variety are found the small British and American airships, using stuck patches only; the French Zodiacs, in which the suspensions are attached to long strips running longitudinally on each side of the envelope, and having reinforced edges to



which the suspension ropes are attached at intervals; the German Parsevals, in which the suspensions are attached to a fabric girdle strip running round the under side of the envelope in a roughly oval curve, the envelope being reinforced by a number of braid strips which pass over the envelope from side to side and serve to conduct the lift of the envelope to the girdle and to relieve the tensions in the envelope fabric.

(*b*) The French Astra-Torres or trilobe variety. In this, the car suspensions pass through gastight joints into the bottom of the envelope on the centre line, and are there connected to fans of smaller ropes which lead up to attachment points on internal suspension strips at the two upper ridges or angles of the trilobe section. The three ridges of the trilobe are maintained in their correct relative position by internal fabric curtains connecting them; these curtains run continuously from end to end of the envelope, and being in a state of considerable tension tend to give a certain measure of rigidity to the form of the envelope.

Table I.—*General Particulars of Three Typical Non-Rigid Airships.*

—	Zero.	C Star.	Parseval.
Gross lift at 68 lb. per 1,000 ft.	4,690 lb.	14,100 lb.	11 tons
Disposable lift when full	1,600 lb.	4,655 lb.	5 tons (estimated)
Overall length ..	143 ft. 6 in.	220 ft. 0 in.	312 ft.
Overall height ..	43 ft. 0 in.	57 ft. 4 in.	70 ft.
Overall width ..	33 ft. 9 in.	45 ft. 10 in.	57 ft.
Total brake horse-power	75 h.p.	360 h.p.	520 h.p.
Speed at full power..	40 m.p.h.	57 m.p.h.	55 m.p.h. (estimated)
Endurance at full power	12 hours	12 hours	25 hours (estimated)
Summary of Weights.			
Envelope and fittings including tail planes, valves, nose stiffeners, &c.	1,922 lb.	5,678 lb.	7,350 lb.
Car suspensions ..	100 lb.	448 lb.	250 lb.
Car *ex* machinery ..	409 lb.	3,319 lb.	2,180 lb.
Machinery installation, including petrol system	590 lb.		3,650 lb.
Total fixed weights	3,021 lb.	9,445 lb.	13,430 lb.

N.B.—Endurances are given for ships initially fully loaded, including armament.

The above types are all successful on service. For small airships up to 150,000 cub. ft. or perhaps 200,000 cub. ft. there is probably nothing gained by departing from the circular section envelope with stuck-patch suspension attachments.

For larger sizes, up to about 400,000 cub. ft., or perhaps 500,000 cub. ft., the Zodiac, Parseval, and Astra types are available. The Astra type has the least overall height, because the suspensions are attached high up inside the envelope, hence lower and cheaper sheds can be used. A special advantage of the Astra type is the facility with which petrol, water ballast, &c., can be suspended directly from the envelope ridges. This is a very valuable feature for large ships. On the other hand there is a large mass of internal rigging difficult to adjust or even to inspect. The trilobe form also has slightly higher air resistance than the circular form. The Parseval type, though somewhat costly, is excellent and keeps its shape better than any other type of which we have experience. The patent rights in this country are held by Messrs. Vickers, who have kindly supplied the data for a design of this type in Table I. The Zodiac type is thoroughly serviceable, and should be cheaply and easily constructed. It has not been tried in this country, and precise data as to its performance cannot be given.

Both the Parseval and the Zodiac airships have naturally greater overall height than the Astra, and this can only be reduced by the use of longer and, therefore, heavier cars, or by using more than one car. The Parseval is also longer than the Astra type and requires a bigger shed. On the other hand, as indicated later, the lower position of the cars gives greater stability and easier control of the air.

For airships larger than 500,000 cub. ft. the non-rigid type certainly can be, and has been used, but its efficiency tends to compare less favourably with the semi-rigid type as size is increased.

In Table I are given the weight statements of some typical non-rigid airships. The large proportion of the fixed weights taken up by the envelope and its fittings is to be noted. About three-quarters of this item is fabric, the weight of which in envelopes of similar form and equal speed, but different capacities, can be expressed generally by the equation—

$$W = K\,\Delta^{\frac{2}{3}}\,(A + B\,\Delta^{\frac{1}{3}} + C\,\Delta^{\frac{2}{3}}),$$

where W = total weight of fabric,
A = weight of proofing per unit area,
Δ = total lift,
K. B and C are constants.

It is to be noted that the equation only applies to envelopes having the same number of plies in the fabric. The use of this equation shows that the weight of fabric for low values of Δ varies at a lower power of Δ than unity. At a value of Δ, which in some cases is about 250,000 cub. ft., W varies as Δ, while for higher values W varies as a higher power of Δ than unity, *i.e.*, the weight of the fabric is an increasing proportion of the total lift. This is one of the facts which ultimately limits the useful size of non-rigid airships.

It is worth emphasising that the strength, and, therefore, also a large part of the weight, of fabric required for an envelope varies directly as the internal gas pressure. One of the objects always before the designer must, therefore, be the adoption of all means tending to reduce the working gas pressure.

This pressure is required for the following purposes: (1) To enable the outer cover to maintain its form against the distorting forces due to various weights. In particular, the car suspensions leading fore and aft from the car introduce a longitudinal drag on the envelope at their points of attachment, and tend to cause buckling of the fabric. This is resisted by the internal pressure.

(2) To support the bow against the external air pressure in flight: at the extreme tip the external pressure is that of the full kinetic head corresponding to the ship's speed, but it falls off rapidly to a slightly negative pressure at a short distance abaft the nose. By local reinforcements, known as bow stiffening, which take the form of curved tubes fitted longitudinally on the outside of the bow from the extreme nose to a point somewhat abaft that at which the pressure is negative, it is possible to keep the nose from being blown in while using a gas pressure considerably less than that of the kinetic head mentioned above. By extending the bow stiffeners sufficiently far aft, and making them of adequate strength, the necessary gas pressure can be greatly reduced at the expense of some additional weight; something can also be done in this direction by selecting a form of bow in which the area of greatest air pressure is as small as possible.

(3) To support the tail planes as rigidly as possible in position, in face of the considerable wind pressure upon them when the rudders and elevators are used, or when the ship is swinging. Here the gas pressure inside the envelope has to maintain the latter sufficiently taut to provide a firm base for the planes, but the pressure necessary for the purpose can be reduced by fitting the planes with very wide bearing surfaces at their inner edge, where they bear against the envelope; increasing the width of these bearing surfaces again means increased weight.

It will be seen from the above that gas pressure may be reduced by various local weights, and that a balance of advantage has to be struck to secure the least total weight. Whatever fittings are provided, however, there is, for each ship, a certain minimum pressure below which we cannot go without risk of buckling the envelope, or blowing in the nose, or loss of efficiency in the tail planes, due to their being inadequately supported. Clearly, the necessary pressure increases with speed and with size of ship.

As this pressure is in any case small, rarely exceeding 40 mm. by water gauge (about 8 lb. per square foot) at the axis, the resistance of the envelope to distortion is not great and extreme care in design is necessary to obtain a flat curve of loads, *i.e.*, to obtain the most

* Paper read before the Institution of Naval Architects, on Thursday, April 10, 1919.

favourable balance between weight and buoyancy at all points along the envelope. It will, however, be seen from the following example that a perfect balance cannot be struck in all conditions.

An airship at her maximum height, with ballonets nearly empty, has a buoyancy curve whose ordinates are proportional to the sectional area of the envelope (see Fig. 2, annexed), and to the lift of gas per cubic foot in the air at that height. The same airship on descending to ground-level without change of weights carried will have her ballonets nearly full of air. The ordinates of the buoyancy curve are determined as before, allowing for the greater air density, but in way of the ballonets the sectional area of these must be deducted from that of the envelope. The total buoyancy is unaltered, but it is now differently distributed. Clearly no system of loading can deal effectively with two such different conditions, and a compromise must be adopted.

A source of much trouble in the past has been the necessity of carrying the weight of the tail planes upon the tapered stern of the envelope, where the buoyancy is naturally low, and the stiffness against longitudinal distortion is much reduced. It has been found that the only satisfactory method is to keep the stern lines full enough to enable the weight of the planes to be locally air-borne when the airship is under her average conditions as regards lift.

It is found that the amount of shearing force or bending moment which the envelope can support continually is very small indeed—the usual effect of such action being a very slow distortion which gradually reaches a maximum in, perhaps, several weeks. For short periods, however, considerable forces can be borne, as is shown by the relative rigidity of the envelope when turning.

The weight of the car and its contents—the crew, machinery, &c., and often also the petrol, oil and water ballast—are suspended from the envelope by means of a number of suspension ropes, so arranged as to distribute the weight over the greater part of the length of the envelope, and to maintain the position of the car, relative to the envelope, unaltered under all conditions of flight. These conditions should include inclinations of the airship at least 30 deg. either way with full propeller thrust acting.

As far as the distribution of the car weights to the envelope is concerned, there is everything to be gained by hanging the car as far as possible below the envelope, as by this means the inclination of the forward and after suspensions is reduced. It is, however, necessary also to transmit most of the engine thrust and, when the ship is inclined, the longitudinal component of the car weights, through the suspensions to the envelope, and this is more conveniently done when the car is close up to the latter. It may be noted that when the car is raised, the forward and after suspensions are inclined at a greater angle with the vertical, and have a greater tendency to place the lower part of the envelope in compression, which is undesirable. This does not, of course, occur to the same extent in the Astra type.

Another consideration which enters into the decision as to the best height at which to rig a car is that of stability. If the car is rigged close up, the airship has less inherent stability, and is not so steady in flight, but on the other hand, she is much more readily and quickly manœuvred by the elevators. Such an airship requires large fixed horizontal planes aft, and relatively small elevators. If the car is rigged low down, the above conditions are reversed, and we shall have an airship which, while less handy for, say, diving downwards to bomb a submarine, is less fatiguing to fly, and can hold her speed better in bumpy weather. In most British airships which have been built for war purposes the cars are slung as close up to the envelope as they safely can be, but for commercial purposes a somewhat lower suspension would be more suitable.

General Remarks.—Non-rigid airships form a class of great utility, which can be given speeds of 45 miles to 60 miles per hour with disposable weight percentages from 33 per cent. to 45 per cent., the lower figures applying to the smaller airships.

They are particularly suitable for short distance flights and for patrol duties. Their chief merits are simplicity, ease and cheapness of production, and low cost of maintenance.

SEMI-RIGID AIRSHIPS.

In the foregoing brief discussion regarding non-rigid airships, it has been seen that the envelope absorbs a considerable part of the total weight, due to the large internal gas pressure required to give the necessary rigidity to the envelope, and also to support the bow stiffeners and tail planes against the aerodynamic forces to which they are exposed during flight.

In semi-rigid airships, a longitudinal keel girder is fitted to the under side of the envelope so as to constitute a rigid, or in some types slightly flexible, backbone.

The whole weight of the car or cars and the disposable weights are suspended from the keel, which in turn is supported by the envelope to which it is attached at many points along its length. The interposition of the keel, therefore, relieves the envelope of all local stresses, shearing forces, &c., due to the car and disposable weights. If continued to the bow and tail the keel also gives effective support to the bow stiffeners and to the tail planes.

The general effect of the keel is, in fact, to relieve the envelope of all the loads which in non-rigid airships have to be met by the use of a relatively high internal gas pressure. As a result it is found possible to fly large semi-rigid airships of over 600,000 cub. ft. with gas pressures at the axis little more than one-half as great as those required in non-rigids of equal capacity and speed. A lighter envelope fabric can, therefore, be used, and sufficient weight is thus saved to compensate entirely for the extra weight of the keel girder. That is to say, the combined weight of envelope and its fittings keel girder, bow stiffeners, and tail planes in a semi-rigid airship may be less than the weight of the corresponding items, exclusive of keel girder, in a non-rigid of equal capacity.

A further point is that, although in a semi-rigid the maintenance of full inflation of the envelope is necessary for rapid flight, the airship can, nevertheless, be brought to land and even flown slowly, with the envelope partly deflated, provided sufficient lift is retained; it becomes profitable, therefore, to divide the envelope into compartments by means of transverse fabric bulkheads, and so to reduce the risk of the airship being lost through an accidental tear in the envelope. This is not feasible in a non-rigid in which loss of pressure means buckling of the envelope, and, in many cases, loss of the ship. The bulkheads also limit the alteration of pressure at the ends due to inclinations of the airship, and this is a further reason for the lower envelope pressure mentioned above.

In recent years the semi-rigid airships have been developed by the Italians alone, who have shown great skill and ingenuity in doing so. Of the two main types one, called the Military type, has been developed by the Italian Government; the other bears the name of Signor Forlanini, of Milan.

The Military type has played a very large part during the war in bombing work over the Austrian lines and in anti-submarine coast patrol. From the design point of view, the most interesting feature is the keel, which is not a self-contained rigid frame, but is a series of compression members jointed together, which form, in conjunction with the wire rigging supporting the car, a beam which distributes the weight of the car along the envelope. The envelope is attached to the joints of the keel by means of a series of wire ropes attached in parabolic form to the lower parts of the envelope so as to concentrate the lift of the latter at the keel joints; the riggings from the car are also attached from the same keel joints, and the profile shape taken up by the keel is such that the forces at each of the joints are in equilibrium. The whole forms a very light and ingenious compensating system by means of which the concentrated weight of the car is distributed along the length of the envelope in such a manner as to produce on the latter simple vertical forces only. The keel at its after ends forms a support for the rudders and elevators, which are carried on a wide gantry under the tail. At the bow the keel also gives assistance to the bow stiffeners; it, therefore, performs efficiently the whole of the functions already outlined as pertaining to the keel of the semi-rigid type. The envelope is compartmented, and has a single ballonet extending the whole length of the bottom without division, it, therefore, insures uniformity of pressure in all the compartments.

The Military type is built in several sizes, all of which are highly satisfactory. It represents almost the most highly developed type of airship in existence.

The particulars of Forlanini airships, given in Table II, have been supplied by Messrs. Sir W. G. Armstrong, Whitworth & Co., who hold the British rights of construction for this type. F5 and F6 have both done excellent work in the war. F8 is in the design stage only.

Special features of the Forlanini type are:—

(1) A rigid triangular keel girder composed of light steel lattice girders running the whole length of the underside of the hull.

(2) A compartmented gasbag, the lift of which is transferred directly to the top of the keel girder at numerous points along its length.

(3) An outer cover which is normally inflated with air, and surrounds the gasbag at a distance of several inches. The ring space between the outer cover and the gasbags form the air ballonet of the airship.

This arrangement has many outstanding advantages, but it should be mentioned that the gasbag is somewhat complicated, and the large amount of fabric employed involves the use of specially light qualities of cloth. An interesting point is that all the Forlanini airships mentioned are specially designed for flying at heights of not less than 13,000 ft., at which height the air density and, consequently, all aerodynamic forces, including propeller thrust, are only about two-thirds of those which would occur at the same speed at ground-level. The keel structure can, therefore, be made lighter than if the airship had been designed for maximum performance at lower altitudes. The principle is a valuable one, and has been adopted in some recent German airships, where, as in the Forlanini type, the object has been to rise to great heights for bombing attacks, and for escape from aeroplanes.

Such airships specially designed for high flying, have had a special value for the Italians in connection with the bombing work which has been carried out over the Austrian lines during the war, but they are not very suitable for commercial purposes, or for coast patrol work. The semi-rigid types can, of course, equally well be designed for use at lower altitudes, but the fixed weights would then exceed somewhat the very low value, viz., 50 per cent. of the total lift, shown by Table II. As regards the limits of size for semi-rigids, the lower limit is said to be about 100,000 cub. ft., but for sizes up to about 400,000 cub. ft. the advantage appears to lie with the non-rigid type on the score of cheapness, simplicity, and rapid production. The upper limit is apparently considered by the Forlanini designers to lie not lower than 1,000,000 cub. ft., and the rigid type is probably superior for greater capacities. The semi-rigid type, therefore, has a special value in that it fills in the gap between the largest efficient non-rigid and the smallest useful rigid airship.

Fig. 2. NON-RIGID AIRSHIP.
CURVES OF BUOYANCY.

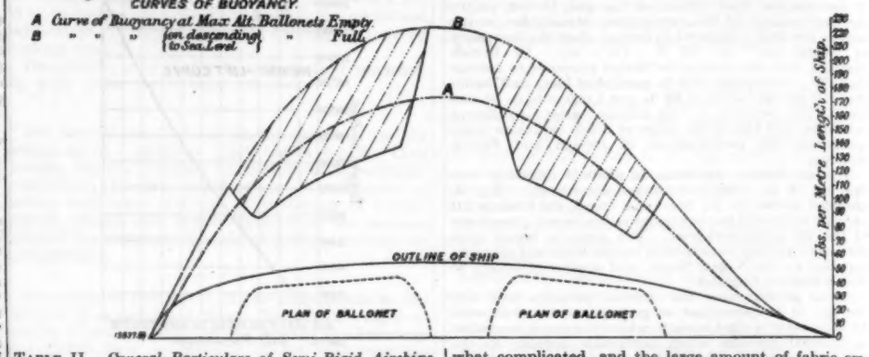

A Curve of Buoyancy at Max Alt. Ballonets Empty
B " " " (on descending to Sea Level) " Full
B
A
OUTLINE OF SHIP
PLAN OF BALLONET
PLAN OF BALLONET
Lbs. per Metre Length of Ship.

TABLE II.—*General Particulars of Semi-Rigid Airships.*

—	F5.	F6.	F8.	M (special).
Type	Forlanini	Forlanini	Forlanini	Military
Maximum diameter, feet	65·6	65·6	75·5	59 (beam)
Maximum length, feet	295·0	295·0	361·0	269·0
Volume within outside envelope, cubic feet	671,000	671,000	1,060,000	441,000
Volume of gasbags, cubic feet ..	628,000	628,000	990,000	441,000
Number of gastight compartments ..	12	12	12	6
Fixed weights, total, tons	9·55	9·74	14·96	7·48
Fixed weight per 1,000 cub. ft. of gas, pounds ..	34·0	34·7	34·0	38·0
Load carried at sea-level, tons.. ..	9·55	9·36	15·04	5·90
Load carried at 13,120 ft. above sea-level, tons ..	3·45	3·24	5·4	—
Number of motors ..	2	4	4	3
Total horse-power of motors at sea-level	480	760	1,400	650
Maximum speed in miles per hour—				
1. At sea-level ..	43·5	45·8	49·7	53·0
2. 6,560 ft. above sea level ..	46·6	50·0	56·0	—
3. 13,120 ft. above sea-level ..	49·7	55·0	62·2	—
Consumption in pounds of petrol and oil at 85 per cent. maximum speed and 13,120 ft. above sea-level, per hour	99·0	143·0	276·0	—
" " " per mile	2·34	3·06	5·22	—
Time in seconds to rise or descend 1,000 ft.	109	109	109	—

RIGID AIRSHIPS.

In the foregoing we have seen the possibilities and limitations of non-rigid and semi-rigid airships. We now come to rigid airships, a type of vastly greater possibilities, and whose limitations as to size are not approached by any airship yet under construction.

In a rigid airship, the whole of the shearing forces and bending moments are sustained entirely by a rigid hull. The envelope, which in a non-rigid supplies the whole form and strength of the airship, has degenerated in the rigid type into a series of weak gasbags which have to be most carefully supported over their whole surfaces to prevent them from bursting.

The following brief description applies especially to a typical rigid airship having the following characteristics:—

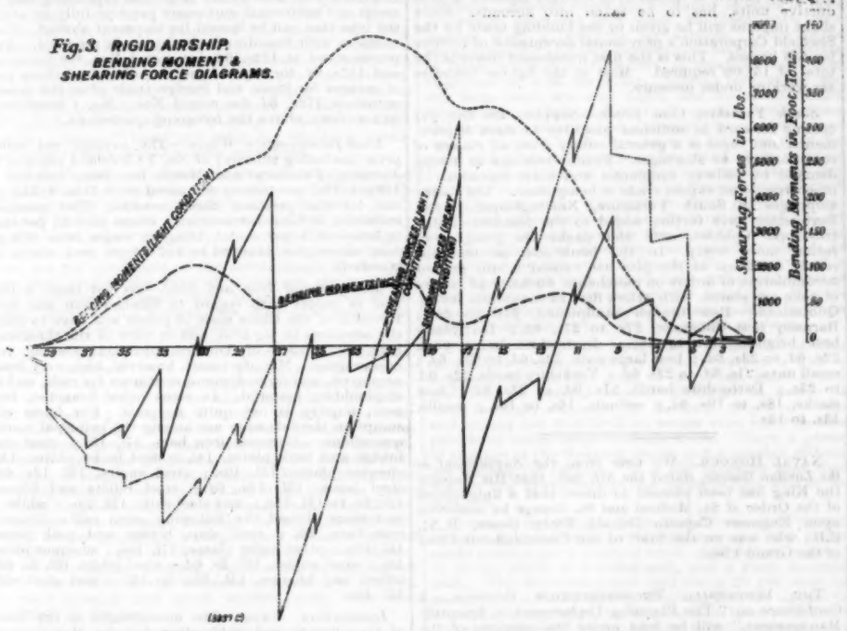
Dimensions = 643 ft. long × 78 ft. 9 in. extreme diameter.
Gasbag capacity = 1,950,000 cub. ft.
Maximum speed = 60 miles to 65 miles per hour.
Total lift = 59·2 tons under standard conditions.
Disposable lift = 30 tons.

The hull structure is composed mainly of triangular lattice girders made of duralumin, none of which is more than 14 in. in extreme depth of section. The hull constitutes, in effect, a skeleton tube of polygonal cross-section, with a short parallel body and long tapered ends forming the bow and stern portions.

There are two main systems of girders: (1) the longitudinals, of which there are 25, nearly equally spaced round the circumference and running from end to end, following the surface of the hull along the angles of the polygon; (2) ring girders called transverse frames running completely round the circumference at about 5-metre intervals. Every alternate one of these ring girders is "a main transverse frame," *i.e.*, it is made especially strong, and fitted with a system of wires arranged on much the same principle as the spokes of a bicycle wheel, so as to maintain rigidly its polygonal shape. The main transverse frames are the equivalent of the bulkheads in a ship, holding the hull to its correct transverse form. The structure is completed by cross bracing wires in all the panels on the surface of the hull between the longitudinal and transverse frames. A structure is thus obtained which behaves as a slightly elastic tube capable of resisting bending moments and shearing forces in a manner similar to that of the hull of an ordinary ship.

Running along the inside of the bottom of the hull is a passage way, at each side of which are stowed the petrol tanks, water ballast bombs, &c. The structure

Fig. 3. RIGID AIRSHIP. BENDING MOMENT & SHEARING FORCE DIAGRAMS.


Shearing Forces in Lbs.
Bending Moments in Foot-Tons.
SHEARING FORCE (LIGHT CONDITION)
BENDING MOMENT (LIGHT CONDITION)
SHEARING FORCE (LOADED CONDITION)
BENDING MOMENT (LOADED CONDITION)

of this passage way is so arranged as to constitute a very stiff keel girder running nearly from the bow to the stern. As the hull bending moments usually produce compression in the lower part of the hull, the stiffening so afforded to the hull at this part is of great value.

The *tail fins, rudders,* and *elevators* are framed with duralumin girders and covered with doped cotton fabric.

The *power cars* and *control car* are all slung from the under side of the hull and are usually held in position by a combination of wire ropes and struts. A typical power car contains a complete machinery unit, including an engine with clutch, spur reduction gear, and two-bladed propeller, radiator, &c. The machinery weighs 8½ lb. to 9 lb. per brake horse-power, and the weight of each machinery car is about 1½ lb. per brake horse-power. The control car is fitted with the usual navigating instruments, rudder and elevator control wheels, controls to the manœuvring gas valves, water ballast, &c. It also contains the wireless cabinet.

The gasbags fill as completely as possible the interior of the hull. Each occupies the space between two main transverse frames, *i.e.*, fore and aft length of 10 m., but a clear ring space about 12 in. in average depth is left between the outside of the gasbag and the outer cover. Each is fitted with an automatic spring-loaded escape valve, and most of the gasbags have also hand-controlled valves at the top for the reducing buoyancy when required, *e.g.*, when landing. The gasbags are made of single-ply cotton fabric lined with goldbeaters' skin. The finished weight per square metre is not more than 160 grams. The total weight of the gasbags is about 4 tons.

An outer cover formed of a series of doped cotton sheets is stretched tightly over the outside of the hull so as to give a smooth exterior.

The above brief description naturally conveys no idea of the innumerable problems constantly occurring in connection with such airships. The outer cover, for instance, appears at first glance to be a very simple matter. In practice, however, it is found to require long experience to obtain the exact tension and the correct degree of stiffness of the doped fabric necessary to ensure durability. The outer cover also has a very important function to perform in screening the gasbags from the heat of the sun and thereby reducing those troublesome variations in lift which result from heating the gas.

Hull Girders.—The hull girders are all made of duralumin. Those which are intended mainly for thrust are equilateral triangles or squares in section. Those intended largely to withstand lateral bending are usually isosceles triangles or rectangles in section, the greatest depth naturally being in the direction of bending. Triangular shaped girders are most widely used and consist of continuous channel members at the three apexes, with bracing pieces, the three faces being made of light stampings from duralumin sheet, and arranged in a series of crosses along each face. The strength of such girders may be indicated by the statement that a girder weighing about 0·8 lb. per foot-run, and of any length up to about 15 ft. can withstand, when subjected free ended to pure compression, a load of 5 tons.

Shearing Forces and Bending Moment Curves.—In Fig. 3 subjoined are shown the curves of shearing forces and bending moments for an airship somewhat of the type described above, in the fully laden and in the light condition.

As might be expected, the more critical condition is the latter. In the loaded condition it is possible to arrange the weights so that in each frame space a fair balance is struck between buoyancy and weight, with the result that shearing forces and bending moments are low. The tail portion is, of course, an exception to this, as rigids, like other airships, are severely stressed by the necessity of carrying the tail fins, rudders and elevators on the fine after part where the buoyancy is naturally low. This is clearly shown on the curves, and is the reason why we avoid, as far as possible, all additional tail weights, and why, also, we avoid placing close to the tail the handling ropes which, when used, would bring additional loads to bear.

In the light condition, we have the tail fins, &c., and the cars appearing as concentrated weights balanced in each case by the buoyancy of several gasbags distributed along the airship. The result is clearly seen in the heavy shearing forces and bending moments produced. Consequently, the scantlings of the longitudinals and of the main hull wiring are determined largely by the estimated maximum values of the bending moments and shearing forces at each point along the length of the airship in the light condition. It is therefore of the first importance to reduce the concentrated weights to a minimum and to maintain in all conditions the most uniform practicable distribution of weights. As the weight of the power cars is chiefly that of the machinery they contain, the importance of reducing machinery weights and of dividing the power amongst as many cars as possible, is manifest. The heavy shearing forces abaft the control and forward power cars appears to be a characteristic feature, and its importance is increased by the fact that it may be greatly accentuated by loads applied to the trail rope during landing or mooring out operations.

In Table III. are given the particulars of early British rigid airships; the steady improvement in performance is notable, and it may be stated that this progress has been well maintained in the most recent types.

In the most recent German airships, of slightly larger capacity than those described above, the disposable lift has been raised to 58 per cent. of the total lift, with maximum speeds of about 75 miles per hour. These airships have been designed specially light for war purposes, but airships intended for long voyages or for commercial purposes generally should be given an increased margin of safety, which would reduce the disposable weight to 50 per cent., or even a smaller proportion, of the total lift. Even so, the performance obtained would be sufficiently remarkable, and there can be no doubt that as further improvement in design and materials are made, still better results may be obtained. In the following example it is shown that an airship of 2½ million cub. ft. capacity can carry 8½ tons of cargo across the Atlantic. If, by improvements, the fixed weights of this airship are reduced by 5 per cent. of their present value, the weight of cargo carried will be increased by 1·9 tons, *i.e.*, 22½ per cent.

The most striking improvement in the commercial value of airships is, however, to be obtained by increased size, as the following example will show. Consider an airship of 2,500,000 cub. ft. capacity, maximum speed 70 miles per hour, and disposable lift 50 per cent. of the total, *i.e.*, about 38 tons. To enable this ship to cross the Atlantic at 55 miles per hour she should carry fuel and oil for, say, 4,500 miles, so as to have a margin in case of meeting contrary winds. Her disposable weight can then be allotted as follows:—

	tons.	Ld.
Crew 30 in number and effects	3	
Water ballast	8	
Petrol and oil	18	
Stores and spares	½	
Carrying capacity for passengers, luggage, food, &c....	8½	
Total	38	

In the above airship, the weights may be divided roughly into groups, as follows:—

1. Weights which may be considered to be a constant proportion of total lift.

	Weight. Tons.	Proportion of total lift.
(a) Hull, fabric, and control	30	
Navigating crew and stores	2	
Water ballast	8	
	40	52½ per cent.

2. Weights varying as brake horse-power.

Machinery	7	
Petrol and oil	18	
Engineers	1½	
Power cars	1½	
	27½	36½ per cent.
3. Passengers, &c.	8½	11 per cent.
Total	76 tons.	

As far as can be seen, the items in group (1) may be taken as a fairly constant proportion, *i.e.*, 52½ per cent. of the total lift over a large range of capacity.

If now we consider an airship of double capacity, *i.e.*, 5,000,000 cub. ft., designed for the same length of voyage and the same speed as above, the machinery weights will be $27\frac{1}{2} \times (2)^{\frac{2}{3}} = 44$ tons, since at equal speeds brake horse-power $\propto \Delta^{\frac{2}{3}}$.

The total lift is then made up as follows:—
Group 1. Hull, &c., 82 tons = 52½ per cent.
Group 2. Machinery, &c., 44 tons = 29 per cent.
Group 3. Passengers, &c., 28 tons = 18½ per cent.

Thus by doubling the capacity we have increased the carrying capacity for passengers, &c., 3·4 times and have raised it from 11 per cent. to 18 per cent. of the total lift. As the running costs of the larger ships will be less than double those of the smaller, *e.g.*, the cost of petrol per voyage will be only 1·6 times as great—it is clear that the larger ship is a far better commercial proposition than the smaller one. In fact the costs per voyage per ton carrying capacity in the 5,000,000 cub. ft. airship would certainly be less than one-half of those of the 2,500,000 cub. ft. airship.

It is desired to lay special emphasis upon this point in order that those who contemplate starting airship services may realise the probable trend of development and make provision accordingly in arranging their sheds and plant. It is, of course, obvious that a shed can at any time be lengthened without excessive cost provided that care is taken to adopt a light form of door which does not require extensive foundations. Alterations to

TABLE III.—*Early British Rigid Airships.*

Airship Class ..	R9.	R23.	R29.	R31.
Designers	Messrs. Vickers	Messrs. Vickers	Admiralty	Admiralty
Date of completion ..	1917	1917	1918	1918
Length, feet ..	526·0	535·0	539·0	614·5
Diameter, feet ..	53·0	53·0	53·0	65·6
Gasbag capacity, cubic feet ..	890,000	942,000	990,600	1,553,000
Total lift, tons ..	27·0	28·6	30·1	47·1
Disposable lift, tons	5·1	5·8	8·2	16·4
Ratio: $\frac{\text{Disposable lift} \times 100}{\text{Total lift}}$	18·9	20·2	27·2	34·8
Total brake horse-power	600	1,000	1,000	1,500
Maximum speed, miles per hour ..	42½	52	55	65
Endurance at two-thirds full power in sea miles ..	500	570	1,070	2,215

Note.—The design of rigid airships for the Admiralty was prepared by Messrs. Vickers under Admiralty supervision up to November, 1915, when the work was transferred to the Director of Naval Construction, Admiralty. In November, 1917, a complete Admiralty Airship Department was formed under the Controller (D.P.A. Department), in which the design work is now carried on. A single airship designed entirely by Messrs. Vickers is, however, now being built at Barrow.

the height and width of the shed are, however, usually impracticable, and these dimensions should, at the start, be dealt with generously.

In discussing the commercial use of airships, the question naturally arises, "How is the heavy cost of operation to be met on the commercial basis?" This question can hardly be discussed in this paper, but there is one thing which we can assert with the support of all human experience, viz., that such a valuable facility for rapid travel as airships afford will not fail to find a wide scope of utility.

YEAR BOOK OF SCIENTIFIC AND LEARNED SOCIETIES.—The thirty-fifth annual issue of this valuable year book, which has just been received, gives particulars of all the scientific and learned societies of Great Britain and Ireland, and of their work during the session 1917-18. Although the condition of the country at the time this edition was in preparation must, in some cases, have rendered the collection of the necessary information extremely difficult, the present volume is no less complete than any of its predecessors, on which point the publishers must be congratulated. It may also be noted that particulars of 26 societies appear in this volume for the first time, and also that music now claims a place among learned societies. A valuable feature of the volume, although not a new one, is the inclusion in it of information regarding the organisation and work of institutions, such as the Imperial Institute, Meteorological Office, National Physical Laboratory, Greenwich Observatory, &c., which cannot be classed as scientific societies. The work of these bodies is, of course, of a similar nature to, and of no less importance than, that carried on by scientific societies, so that it rightly finds a place in a volume which may be regarded more as a record of scientific work than a mere list of societies. The year book is published by Messrs. Charles Griffin & Co., Limited, 7, Exeter-street, London, W.C. 2, and its price is 9s. net.

THE INSTITUTION OF AUTOMOBILE ENGINEERS.—A very interesting meeting of the Institution of Automobile Engineers was held on Wednesday, April 2, when Mr. Opperman read a paper on "Electric Vehicles." An excellent discussion followed in which a number of well-known men in the electrical industry took part, and the leading idea appeared to be that the electric vehicle did not in any way trench upon the ground which can be covered by internal combustion and steam vehicles. It was very strongly laid down by those who had had experience of the electric vehicle that its metier was for comparatively short journeys in towns and on good roads. The automobile engineer should not lose sight of the strong recommendation of one of the speakers that they should go carefully into the question of the construction of the electric vehicle as a side issue. Another good meeting of the Institution was held at Birmingham the following day when Captain Smith-Clarke described the difficulties experienced in tuning up aeronautical engines when these had been got on to quantity production. He finally upset the almost universally held opinion that each motor has its own individuality by pointing out that the difference in performance of apparently similar engines was due almost entirely to the fact that any two carburettor jets supposed to be of the same area do in fact vary between very wide limits. He went on to describe the methods adopted by the Aeronautical Inspection Department for calibrating jets, and illustrated the instruments used and also those used for reading the actual consumption in pints, per brake horse-power per hour at any moment during the brake test. It is undoubtedly of great importance that the information collected by Captain Smith-Clarke should be well known to automobile engineers.

BRITISH INDUSTRIES EXHIBITION IN ATHENS.—We understand that an exhibition of British manufactures in Athens, originally suggested by a delegation of Greek business men who visited the industrial areas of this country last autumn, under the auspices of the Federation of British Industries, is now being organised by that body. The "Zappeion" building, in the centre of Athens, has been lent for the purpose by the Greek Government, who are in full sympathy with the scheme, as also is Lord Granville, His Majesty's Minister at Athens. The Federation's special commissioner, who has visited Greece, found an extraordinary shortage of all kinds of manufactured goods, not only in Greece but also in the neighbouring Balkan and Levantine countries. With the Greek Government and people now strongly Anglophile the moment seems particularly opportune for British manufacturers to secure this trade, which before the war was principally in German and Austrian hands. The policy of the Greek Government is to develop the existing agriculture of the country as much as possible, and to encourage the inauguration of manufacturing industries which Greece, at present, does not possess. The machinery section of the exhibition will therefore be of considerable importance. In addition to the "Zappeion" Building the Government has granted the use of a large piece of land on which extension buildings are being erected to house the larger exhibits that cannot be conveniently shown in the Zappeion, and this land will also be available for practical demonstrations of agricultural and other machinery. Although the main object of the exhibition is to promote British trade with Greece, arrangements are being made to attract all classes of buyers from many or all of the Balkan States and the Levant, and in this way it is hoped to secure for British manufacturers a large share in the trade with the Near East generally. The address of the Federation of British Industries is 39, St. James's-street, London, S.W. 1.

NOTES FROM SOUTH YORKSHIRE.

SHEFFIELD, Wednesday.

Iron and Steel.—A healthy undertone exists, despite the fact that inquiries are far more numerous than actual orders, and that in certain of the heavier branches the volume of business is barely sufficient to maintain half-time production. The supply of foundry iron is far from satisfactory. Coal troubles and the removal of Government subsidies are reacting unfavourably on the output and distribution of basic materials of all classes, and makers of finished products declare themselves to be badly handicapped in quoting against foreign producers, especially for overseas contracts for reconstruction work in France and Belgium. The recent pressure on output in armament production has given place to a much quieter state of affairs, but unemployment is held within normal bounds by the absorption of semi-skilled hands in the lighter steel trades, where work is plentiful and wages remunerative. Special attention is being paid to the production of railway steel and locomotive parts, for which makers anticipate a heavy demand when labour conditions in allied industries are more settled, and manganese steel for tramway track work. A very satisfactory call for the latter is resulting from the latest requirements of provincial corporations. Crucible steel is apparently in diminished request, judging from the slackness at local furnaces, but the fact that the number of furnaces has been materially increased and that output is spread over a larger number of productive units, has to be taken into account. Some slight impetus will be given to the building trade by the Sheffield Corporation's provisional acceptance of tenders for 653 houses. This is the first instalment towards the total of 15,000 required. Most of the lighter branches are working under pressure.

South Yorkshire Coal Trade.—Supplies are not yet coming forward in sufficient quantity to meet requirements, and there is a general outcry from all classes of consumers as to shortages. Steam coals are in strong demand by railway companies and blast furnaces. A much restricted export trade is being done. The recent stoppages in South Yorkshire, Nottinghamshire and Derbyshire have further added to the troubles of distributors. Cobbles, nuts and slacks are going away rather more freely. In the house-coal section, the recent set-down at the pits has caused a still greater accumulation of orders on merchants' books. All classes of coke are scarce, with prices firm at maximum levels. Quotations:—Best branch handpicked, 27*s.* to 28*s.*; Barnsley best Silkstone, 27*s.* to 27*s.* 6*d.*; Derbyshire best brights, 25*s.* to 26*s.*; Derbyshire house coal, 22*s.* 6*d.* to 23*s.* 6*d.*; best large nuts, 22*s.* 6*d.* to 23*s.* 6*d.*; small nuts, 21*s.* 6*d.* to 22*s.* 6*d.*; Yorkshire hards, 22*s.* 6*d.* to 23*s.*; Derbyshire hards, 21*s.* 9*d.* to 22*s.* 9*d.*; best slacks, 18*s.* to 19*s.* 6*d.*; seconds, 16*s.* to 18*s.*; smalls, 13*s.* to 14*s.*

NAVAL HONOUR.—We note from the *Supplement to the London Gazette*, dated the 5th inst. that His Majesty the King has been pleased to direct that a knighthood of the Order of St. Michael and St. George be conferred upon Engineer Captain Donald Percy Green, R.N., C.B., who was on the Staff of the Commander-in-Chief of the Grand Fleet.

THE INDUSTRIAL RECONSTRUCTION COUNCIL.—A Conference on "The Planning Department in Scientific Management," will be held under the auspices of the Industrial Reconstruction Council on Tuesday, April 15, at 5.30 p.m., in the Hall of the Institute of Journalists, 2 and 4, Tudor-street, E.C. 4. The opening address will be given by Mr. James F. Whiteford, after which will follow questions and discussion. No tickets are necessary. The first lecture of the third series arranged by the Industrial Reconstruction Council will be held in the Saddlers' Hall, Cheapside, E.C. 2, on Wednesday April 16. The chair will be taken at 4.30 p.m. by Mr. E. J. P. Benn, chairman of the Industrial Reconstruction Council, and a lecture on the "Industrial Situation" will be delivered by Mr. Stephen Walsh, M.P. Applications for tickets should be made to the Secretary, I.R.C., 2 and 4, Tudor-street, E.C. 4.

INSTITUTION OF LOCOMOTIVE ENGINEERS, LEEDS CENTRE.—The meeting of the Leeds Branch of the Institution of Locomotive Engineers, held on the 25th ultimo, took the form of a general discussion on "Engine Failures." The subject of tube troubles was first dealt with in a paper by Mr. Groom, who referred to the causes of, and remedies for, leakage, breakage, pitting and collapse of tubes in locomotive boilers. Many of the troubles, he thought, would disappear if steel fireboxes could be successfully employed with steel tubes welded into the tube plate. Considerable discussion followed this paper. The next matter referred to was crank-pin failures, and Mr. Mitchinson, who opened the discussion, gave details of the failures which had occurred in the past, and explained the means adopted to prevent such failures. After trying many different kinds of steel for crankpins he said that they were now being made of case-hardened Yorkshire iron. Another frequent cause of engine failure, viz., overheated bearings, was dealt with very fully by Mr. Hamer, who stated that the causes of this particular trouble could generally be attributed to overloading, either in the vertical or horizontal direction, uneven distribution of lubricant, or the presence of foreign matter or water in the bearing. Various points for consideration were given by the speaker with a view to remedying these matters, and after a brief discussion the meeting terminated.

NOTES FROM CLEVELAND AND THE NORTHERN COUNTIES.

MIDDLESBROUGH, Wednesday.

The Cleveland Iron Trade.—The Government subsidies to pig-iron producers cease at the end of this month, and with their withdrawal it is expected that official control of prices of pig-iron will expire. Makers have consequently been considering the question of future rates, and have agreed on fixed minimum selling prices of pig-iron for the months of May and June. The new prices of Cleveland pig-iron, whilst they represent a reduction on present export prices, are 45*s.* per ton above the present prices for home sales. At present, however, a drawback of 50*s.* per ton on export rates has to be paid to the Government, and this, of course, will be discontinued when subsidies are withdrawn at the end of April. Naturally, home consumers are clamouring for deliveries this month at the lower rates. April quotations stand: To home consumers, No. 3 Cleveland pig-iron, No. 4 foundry and No. 4 forge, 95*s.*, and No. 1 Cleveland pig-iron 99*s.*; and to customers abroad, No. 3 and the lower qualities 145*s.* and No. 1 149*s.*; whilst makers' fixed minimum quotations for May and June for both home and foreign trade are 140*s.* for No. 3 and the lower qualities, and 144*s.* for No. 1.

Hematite Iron.—Supply of East Coast hematite continues a good deal more than to satisfy home demand. Inquiries from abroad are large and expanding, and the needs of Continental customers promise fully to absorb the iron that can be spared for shipment abroad. Some business with Scandinavia is this week reported. April prices stand at 122*s.* 6*d.* for mixed Nos. for home use, and 172*s.* 6*d.* for export, and the minimum selling price of makers for home and foreign trade after the present month is 172*s.* 6*d.* for mixed Nos. No. 1 hematite is half-a-crown above the foregoing quotations.

Blast-furnacemen's Wages.—The average net selling price (including subsidy) of No. 3 Cleveland pig-iron for January, February and March has been certified at 118*s.* 4·75*d.* per ton, as compared with 118*s.* 6·21*d.* per ton for the previous three months. This means a reduction in blast-furnacemen's wages of 0·25 per cent. (quarter of 1 per cent.), bringing wages from 108 per cent. above the standard to 107·75 per cent. above the standard.

Manufactured Iron and Steel.—As yet there is little new to report with regard to finished iron and steel. Revision of the whole scale of prices will have to follow the advances in pig-iron, and in view of the threatened keen competition of America, prospects are not very encouraging. Manufacturers, however, keep very busily employed, and large demand continues for rails, and for shipbuilding material. In some other branches, however, inquiry is not quite so good. For home consumption the following are among the principal market quotations:—Common iron bars, 17*l.* 15*s.*; steel ship, bridge and tank plates, 14*l.*; steel boiler plates, 15*l.*; chequer plates, 15*l.* 10*s.*; steel angles, 13*l.* 12*s.* 6*d.*; steel joists, 13*l.* 12*s.* 6*d.*; steel billets and blooms, 12*l.* 5*s.* to 12*l.* 15*s.*; and steel rails, 13*l.* 10*s.*; whilst to customers abroad the following rates rule: Common iron bars, 20*l.*; steel ship, bridge and tank plates, 16*l.* 10*s.*; steel boiler plates, 17*l.* 10*s.*; chequer plates, 18*l.*; steel angles, 16*l.* 2*s.* 6*d.*; steel joists, 16*l.* 2*s.* 6*d.*; billets and blooms, 13*l.* 10*s.* to 15*l.*; and steel rails, 15*l.* 10*s.*

Ironworkers' Wages.—The accountants to the Board of Conciliation and Arbitration for the Manufactured Iron and Steel Trade of the North of England have certified the average net selling price of iron bars and angles for the two months ending February 28 last at 16*l.* 12*s.* 11·3*d.* per ton. In accordance with instructions from the Ministry of Munitions this average realised price should be increased in respect of subsidies granted to pig-iron makers by the sum of 20*s.* per ton on sales for home consumption. After making this adjustment the ascertainment is increased to 17*l.* 12*s.* 9*d.* For the previous two months the average net selling price was 15*l.* 10*s.* 9·11*d.* per ton. Under the ascertainment puddling and other forge and mill wages are increased by 12½ per cent.

Consett Steelworkers' Wages.—The average net selling price of steel plates at Consett for the three months ending February 28 last is certified at a figure which increases steel millmen's wages for April, May and June to 87½ per cent. above the standard, which is 5 per cent. above the wages prevailing in the preceding three months. This 5 per cent. advance is wholly due to the ordinary operations of the scale, and not by inclusion of subsidy. Wages at Consett have advanced 75 per cent. since the outbreak of war, and the previous highest point they reached was in December, 1900, when the rate attained 27½ per cent. above the standard.

Coke.—Coke keeps strong. The 5*s.* 7*d.* subsidy on furnace coke stops this month. Little new business is passing, but deliveries to local blast furnaces are maintained on a satisfactory scale.

BRITISH SCIENTIFIC PRODUCTS EXHIBITION.—The British Science Guild has been encouraged to organise an exhibition this year by the success which attended that held at King's College last summer, and the more recent exhibition at the College of Technology, Manchester. The exhibition is to be held at Central Hall, Westminster, from July 3 to August 5. The exhibits will be divided into the following sections: Agriculture, Aircraft, Chemistry, Education, Electrical Appliances, Engineering, Fuels, Medicine and Surgery, Metallurgy, Paper, Illustration and Typography, Physics and Textiles.

NOTES FROM THE NORTH.

GLASGOW, Wednesday.

Scotch Steel Trade.—In the steelmaking industry business on home account continues to run on active lines, and the output is as satisfactory as could be expected under existing circumstances. Rumours float about that further troubles lie ahead due to the shortage of coal, the difficulty of procuring adequate supplies of raw material, and the increased cost on values rendered necessary by the new three-shift day. It is, perhaps, quite safe to assume that, when things settle down, as they must in the very near future, the re-adjustment will follow as a matter of course. The works are all busy, the bulk of the production being monopolised by the home consumer, for as yet steel-makers have little opportunity of shipping the material so eagerly sought for by overseas buyers. In a very short time, if all goes well, the export trade may be expected to make astonishing developments. A move was made towards an advance in price, but this has been set aside for another month in order that producer and consumer may arrive at such an arrangement as shall best suit the interests of the steel-making industry. With the increasing construction of mercantile shipping, the demand for ship plates, sections and other material is steady and constant.

Malleable Iron Trade.—The change to the eight-hours' day scheme has had a rather disconcerting development in the malleable iron trade, and in consequence the rolling mills have been stopped. This has meant a serious loss both to employer and employed. This difficulty, which affects the wage question, is all the more unfortunate when the satisfactory conditions under which the men worked are taken into account. Every effort is being made to re-adjust matters as speedily as possible, especially as there is a large volume of work for the home trade waiting to be put through, mainly "Crown" bars, and strips for the tube works. No export trade is being done meantime.

Scotch Pig-iron.—Despite the fact that pig-iron has now reached the top price the greatest activity prevails and every ton produced finds a ready market. These inflated rates, which smelters affirm are absolutely unavoidable when the price of raw material and the advanced cost of production are taken into consideration, are not conducive to the development of the iron and steel trades, the basis of which are pig-iron, but it is confidently expected that before very long something more like the normal rate may rule once again. Foundry iron is much in request.

New Shipping.—During the past week some important launches have been made, notable among which was that of the War Pioneer, a standard steamer of the "A" class, built by the Fairfield Shipbuilding and Engineering Company, Limited, Govan, to the order of the Shipping Controller. From Messrs. Charles Connell and Company's yard at Scotstoun the Masirah, built to the order of Messrs. T. and J. Brocklebank, Limited, Liverpool, took the water. With a deadweight carrying capacity of about 10,500 tons, the new vessel is to be supplied with triple-expansion engines by Messrs. Dunsmuir and Jackson, Limited, Govan. Another new vessel is the Moorfowl, a single-screw steamer ordered by Messrs. G. and J. Burns, Limited, from Messrs. A. and J. Inglis, Limited, Pointhouse, to supplement their Royal Mail service between Scotland and Ireland. A mine-sweeper and some smaller craft were also included in the list.

ELECTRIC HEATING FOR THE CONCENTRATION OF SULPHURIC ACID.—Assuming that the concentration of 100 kg. of sulphuric acid of 50 deg. Baumé up to 65·6 deg. would require 20 kg. of anthracite in platinum stills and 10 kg. in Kessler apparatus, S. Pagliani (*Annali Chemica*, April, 1918, page 134) finds that, working with platinum electrodes in enclosed apparatus of quartz, iron or lava, the cost of electricity to coal would be as 9 : 5.

THE WINTERTHUR MOTOR PLOUGH.—The motor plough of the Schweizerische Lokomotiv und Maschinenfabrik, at Winterthur, Switzerland, combines tractor, motor and plough on one truck, and is driven by its own power, developed by a 30-h.p. four-cylinder engine which may work with crude oil. The shafts of the differential gearing are provided with ball bearings, and one man operates through the gearing the fore-and-aft movements and the lowering and raising of the plough. All the three tractor wheels run on the unploughed ground. The total length of the plough is 5·5 m., the width 2·1 m., the height 1·9 m., the tractor with motor weighs 2,800 kg., the plough with three blades 800 kg.

RADIOTELEGRAPHY AND HIGH-FREQUENCY ENGINEERING.—The following is a complete list of the members of the Wireless Sectional Meetings Committee (for radiotelegraphy and high-frequency engineering) of the Institution of Electrical Engineers: The president (*ex-officio*); Major E. A. Barker, M.C., R.E.; Mr. Charles Bright, F.R.S.E.; Dr. W. Eccles; Professor G. W. O. Howe; Admiral Sir H. B. Jackson, F.R.S.; Mr. W. Judd; Sir Oliver Lodge; Professor E. W. Marchant; Dr. G. Marconi; Major J. Erskine Murray, R.A.F.; Mr. J. Sayers; Major T. Vincent Smith, R.A.F.; Mr. A. A. Campbell Swinton, F.R.S.; Mr. J. E. Taylor; and Captain J. K. Im Thurn, R.N. (nominated by the Admiralty); Lieutenant-Colonel A. D. Warrington-Morris, O.B.E., R.A.F. (nominated by the Air Ministry); Lieutenant-Colonel W. Ll. Evans, C.M.G., D.S.O., R.E. (nominated by the War Office).

NOTES FROM THE SOUTH-WEST.

CARDIFF, Wednesday.

The Local Coal Markets.—For the first time for some weeks past there are practically no stoppages in the South Wales coalfield. Despite this and increased outputs free coals for export are practically unobtainable, because of exceptionally heavy allocations to inland consumers, whose need for supplies is pressing, and also to large arrears which have accumulated for Allied countries during the unauthorised strikes of a fortnight ago. The ballot of miners begun to-day, and it is expected that it will favour an acceptance of the Government's terms as recommended in the Sankey report. The claims of the coal trimmers and coal tippers for a shorter working week and increased pay have been settled and agreements have been signed which come into operation as to pay from Monday last, and for a shorter working week from next Monday. The supply of tonnage in dock is ample to meet the requirements of exporters, and now that the trimmers and tippers are only going to work two eight-hour shifts a day instead of continuously, it is feared that the tipping capacity of the various ports will be diminished by the shorter hours unless the break between the shifts are utilised to their fullest extent for the clearance of empty wagons and the marshalling of loaded trucks. The authorities are very sparingly granting the release of coal for export and for neutral countries, it is almost impossible to get supplies for shipment this side of the holidays. Already there are a number of ships in dock previously chartered and some of these have been waiting over a fortnight for cargoes. Little hopes are entertained of much releasing of coals for neutrals, as lately a number of ex-German steamers have been chartered to load for Italy. Steam, bituminous and dry large coals are very tight, and the same remark applies to washed and through coals. Small steam and dry qualities are also extremely scarce with good inquiry. Lately there has been a better inquiry for coke, and manufacturers have improved their position. It is announced that at the end of this month the control exercised over coke so far as inland business is concerned, is to be removed. The present fixed price for coke for inland purposes is 42*s.* 6*d.* for furnace, and 55*s.* 6*d.* for foundry, which includes the subsidy of 5*s.* granted by the Ministry of Munitions, and which is also to be terminated at the end of the month. Patent fuel is in good demand, and makers have sufficient orders to keep them going this side of the holidays. Pitwood remains scarce, though there has been a little improvement in arrivals during the last couple of days.

Newport.—There has been heavy allocations of Monmouthshire steam coals for inland purposes, and as large supplies are also going to the Allies, there is little coal left for general export. Collieries in nearly all cases are fully stemmed for the next couple of weeks, and buyers find it difficult to secure even small isolated parcels of either large or small coals. There is plenty of tonnage at the Newport docks, and a number of boats are waiting for cargoes. It is not expected that there will be any abatement in the pressure this side of the holidays.

Trimmers and Tippers Wages and Hours.—In February last the Bristol Channel coal trimmers and coal tippers made a claim for a working week of 86 hours, made up of 10-day shifts of 8 hours each, and a short Saturday shift. The trimmers asked also for a 20 per cent. increase on their total weekly earnings, and the tippers for a minimum wage of 5*l.* 5*s.* Negotiations have been active during the past six weeks, and on Monday an agreement was reached whereby the working hours from Monday next will be from 8 a.m. to 5 p.m., Mondays to Fridays inclusive, and from 9 p.m. to 0 a.m. Mondays to Saturday mornings inclusive, with an hour's break in each shift for meals. The Saturday shift will be from 8 a.m. to 12 noon, making an 84 hour week. The trimmers have been granted a 20 per cent. increase in their weekly earnings, and the tippers a minimum of 3*l.* 19*s* per week, and 20 per cent. will be added to their weekly earnings. The new rates of pay became operative from Monday last.

Shipowners and ex-German Ships.—The Cardiff Shipowners' Association have decided to make representations to the Ministry of Shipping regarding the allocation of ex-German ships, as they consider that the Bristol Channel has been overlooked in the matter. So far only four vessels have been allocated to Cardiff owners for management, namely, two to Messrs. Evan Thomas, Radcliffe and Co., and two to Messrs. Morel, Limited.

Tinplate Annealers Tender Notices.—The annealers throughout the South Wales tinplate trade have given 28 days' notice to terminate contracts, in view of their dissatisfaction with the recent advance of 1*s.* 6*d.* per 100 boxes granted to them. The matter will be discussed at the next meeting of the Tinplate Workers' Executive, and failing a settlement the whole of the tinplate trade will be brought to a standstill.

IRON ORE SHORTAGE IN RHENISH WESTPHALIA.—The ore famine in the Rhenish Westphalian iron works, according to German journals, is becoming more pronounced almost every day. Some 30 blast furnaces have already closed down, and if the supply of minette ore from Lorraine cannot soon be resumed, it is said that the whole industry will come to a standstill. Negotiations for supplying Lorraine and Luxemburg with coal in exchange for ore have not led to any result. For several weeks coal and coke amounting to some 7,000 tons a day are said to have been sent from the Kuhr district to Lorraine and Luxemburg, and it would be possible to bring back a slightly larger quantity of minette ore; but so far this has not been done.

NOTICES OF MEETINGS.

THE JUNIOR INSTITUTION OF ENGINEERS.—Friday, April 11, at 7.30 p.m., at 39, Victoria-street, Westminster, S.W. Paper by Mr. F. H. Taylor (Member), "The Training of the Disabled Man from the Electrical Engineer's Point of View."

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.—Saturday, April 12, at 2 p.m., in the Wood Memorial Hall, Newcastle-on-Tyne. General Meeting. The following paper will be read or taken as read: "Coal-Cutting by Electricity and Timbering at Cannock Chase Colliery," by Mr. W. P. Cheung, B.Sc.

THE INSTITUTION OF ELECTRICAL ENGINEERS.—Monday, April 14, at 7.30 p.m., an informal meeting will be held in the Rooms of the Chartered Institute of Patent Agents, Staple Inn Buildings (South Block), close to 325, High Holborn, W.C., when Dr. R. D. Gifford will open a discussion on "Electrical Instruments."

INSTITUTION OF PETROLEUM TECHNOLOGISTS.—Tuesday, April 15, at 5.30 p.m., at the House of the Royal Society of Arts, John-street, Adelphi, W.C. 2. Sir Frederick W. Black, K.C.B., will deliver his Presidential Address on "Some War Problems of Petroleum Supply," after a valedictory address by Mr. C. Greenway. The chair will be taken by Mr. C. Greenway.

THE ROYAL METEOROLOGICAL SOCIETY.—Wednesday, April 16, at 5 p.m., at 70, Victoria-street, Westminster. Papers to be read: (1) "Rainfall in England: The True Long-average as Deduced from Symmetry," by Mr. Alfred A. Barnes, F.R.Met.Soc., Assoc.M.Inst.C.E.; (2) "The Secular Variation of Rainfall," by Mr. C. E. P. Brooks, M.Sc., F.R.Met.Soc.

THE LIVERPOOL ENGINEERING SOCIETY.—Wednesday evening, April 16, at 8 p.m., at the Royal Institution, Colquitt-street, when a paper will be read by Professor T. B. Abell, R.C.N.C. (retired) M.I.N.A., entitled: "Some Aspects and Developments of Mercantile Shipbuilding under War Conditions."

MESSRS. R. W. HAWTHORN, LESLIE AND CO., LIMITED.—In the article on the "War Development of the Torpedo Boat Destroyer" which appeared on page 362 *ante*, we omitted to include the name of this firm as builders of the machinery of the destroyers constructed by them. At their engine works, at St. Peter's, Newcastle-on-Tyne, they completed, during the war period, machinery for 14 of the destroyers built by them, while at the same time they were constructing machinery for battleships, cruisers, sloops, standard vessels, monitors, and trawl mine-sweepers. The Marksman, Montrose and Stuart, included in their list of vessels built are of the "Leader" class.

CANADIAN ENGINEERING STANDARDS ASSOCIATION.—We read in *The Board of Trade Journal* that the Canadian Engineering Standards Association has recently been incorporated, with head offices at Montreal. The chief objects of the Association are to co-ordinate the efforts of producers and users for the improvement and standardisation of engineering materials; and to prepare and promote the general adoption of standards in connection with engineering structures, materials and other matters and things, and from time to time to revise, alter and amend the same. The following distinguished professional men are listed as the incorporators: Sir John Kennedy, Dr. Robert Ruttan, Dr. John Bonsall Porter, Richard John Durley, and Henry Hague Vaughan all of Montreal. The operations of the corporation are to be carried on without share capital.

OIL IMPORTS.—Speaking of the remarkable work which had been done during the war in connection with the import of oil into this country for the Navy and other purposes, Sir Frederick W. Black, of the Admiralty, speaking at the annual lunch of the Commercial Motor Users' Association on the 2nd inst., gave the following comparative figures:—

	1913. Tons.	1918. Tons.
Motor transport spirit ...	336,193	643,582
Kerosene	628,565	592,085
Lubricating oil	271,850	408,977
Gas oil	244,258	152,147
Fuel oil	380,249	2,369,427
Totals	1,861,115	5,166,218

MALLEABLE IRON.—In the course of a paper which he read on November 7, 1918, before the Birmingham Metallurgical Society, Professor Turner gave interesting facts on the history, the manufacture, treatment and uses of malleable iron. From this we take the following two points: To French scientists, Professor Turner stated, we turn for the classic contributions to our knowledge alike of the "European" system (due to Réaumur), and of the "Black Heart" system of malleableising. In the original, or "European" process, the carbon is not only set free, but is also to a greater or less extent" actually oxidised or burnt away. In the "Black Heart" process little oxidisation occurs, except in the outer edges of the casting. In either case, it is essential to start with white iron, hard, brittle and free from graphite. In the "European" process, the castings are embedded in oxide of iron and heated to a temperature of 900 deg. or 950 deg. C., and they need not be sulphur free. In the "Black Heart" process, the temperature used is about 750 deg. C., and the proportion of sulphur present must be low.

THE TURBINES OF H.M.S. "REPULSE."

CONSTRUCTED BY MESSRS. JOHN BROWN AND CO., LIMITED, CLYDEBANK.

(*For Description, see Page* 461.)

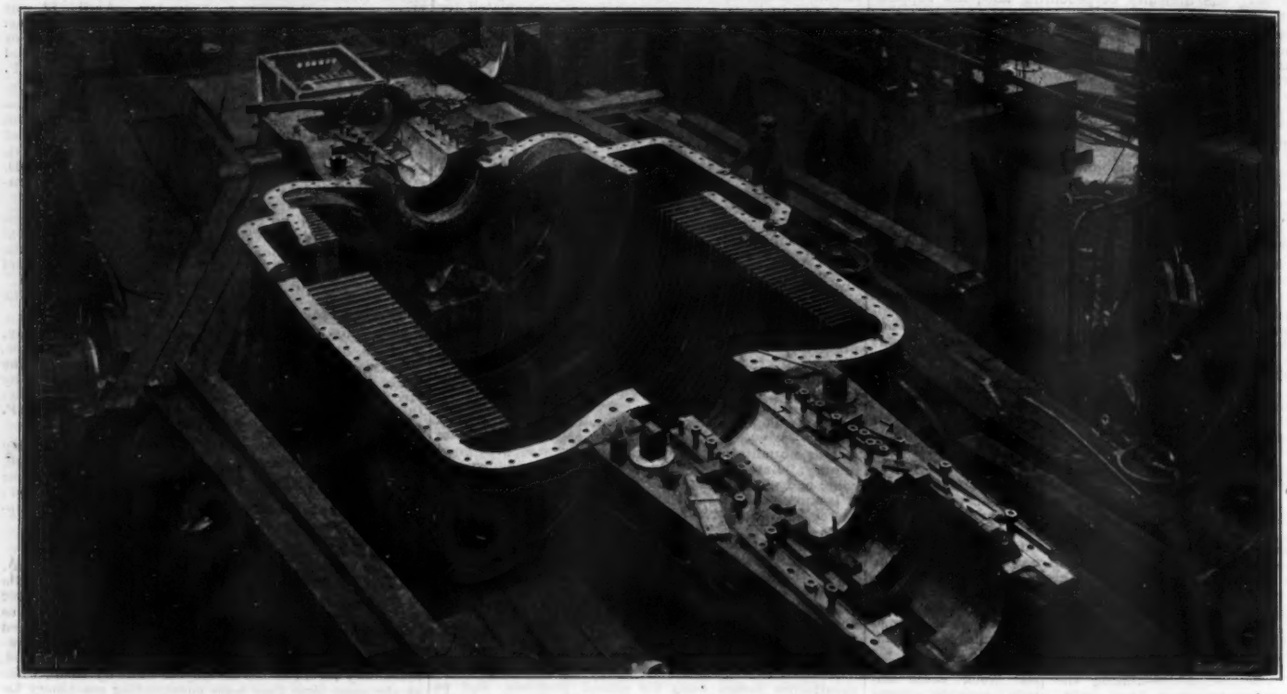


FIG. 15. THE BOTTOM HALF CASING OF THE LOW-PRESSURE AHEAD AND ASTERN TURBINES WITH THE BLADING IN PLACE.

FIG. 16. LOW-PRESSURE DIRECT-DRIVE TURBINES OF "REPULSE" AND LOW-PRESSURE GEARED DRIVE TURBINE OF ANOTHER VESSEL. RATIO OF POWER 3 : 2.

H.M. BATTLE CRUISERS "RENOWN" AND "REPULSE."

(*For Description, see Page* 461.)

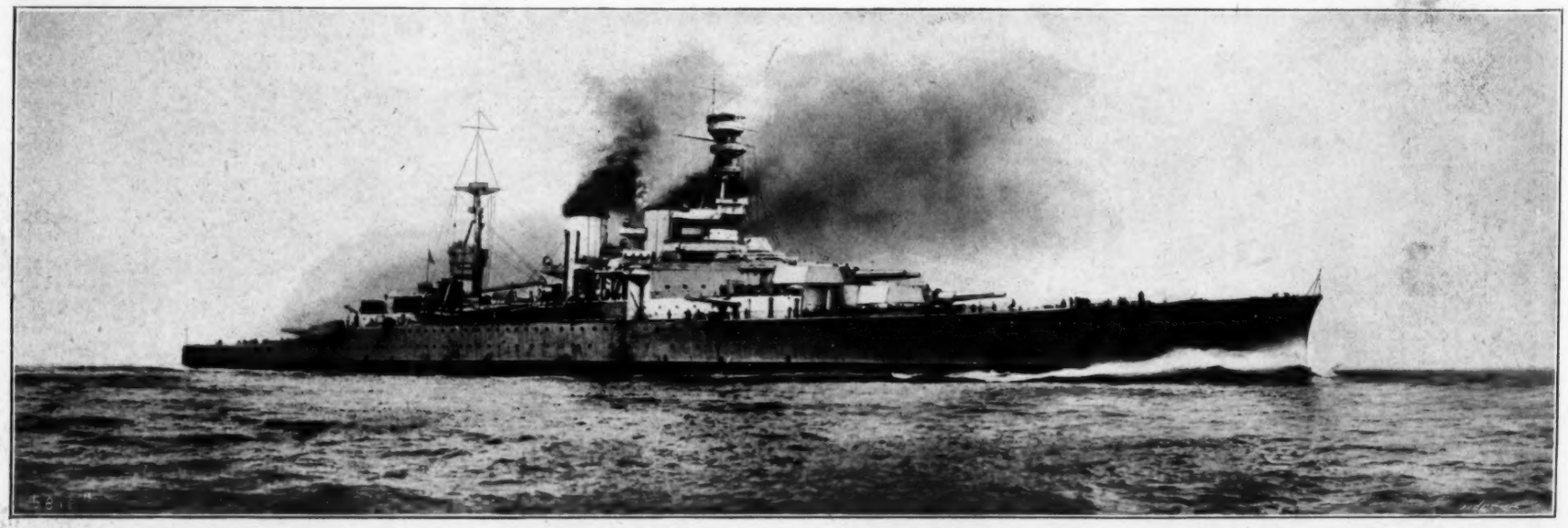


FIG. 1. H.M.S. "RENOWN"; MESSRS. THE FAIRFIELD SHIPBUILDING AND ENGINEERING COMPANY, LIMITED, GOVAN, GLASGOW.

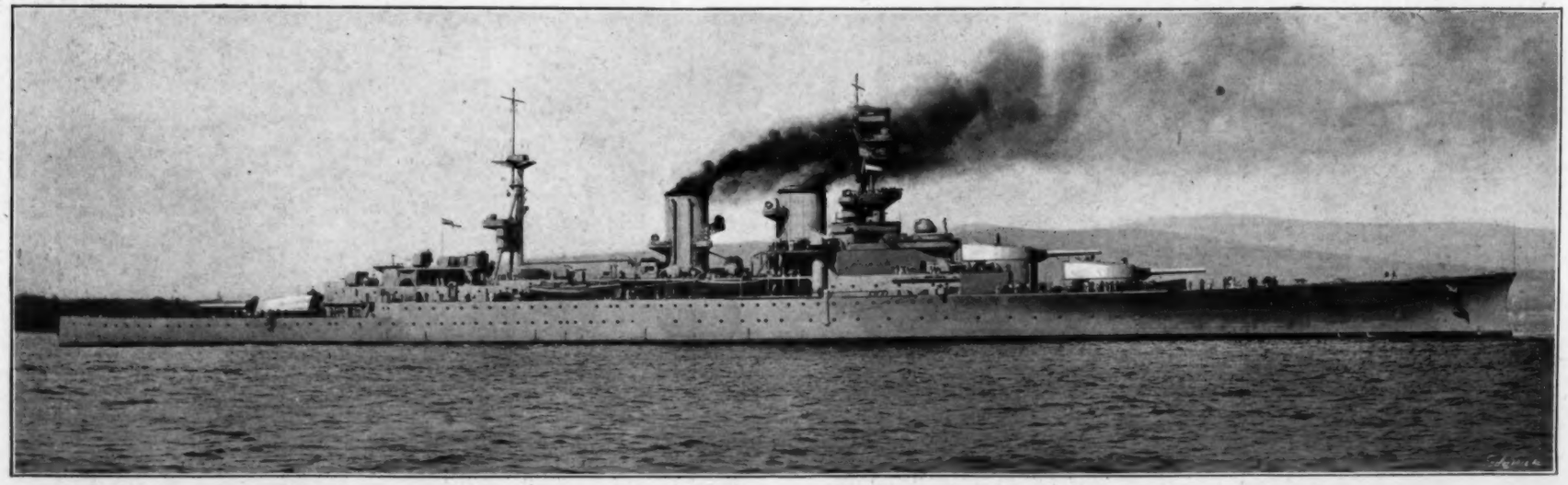


FIG. 2. H.M.S. "REPULSE"; MESSRS. JOHN BROWN AND CO., LIMITED, CLYDEBANK.

(*To face page* 460.)

H.M. BATTLE CRUISER "REPULSE."

CONSTRUCTED BY MESSRS. JOHN BROWN AND CO., LIMITED, CLYDEBANK.

(*For Description, see Page* 461.)

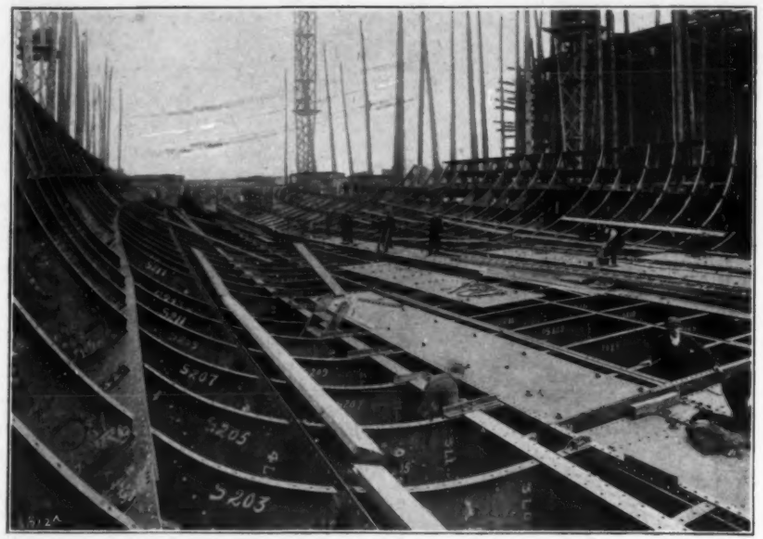


FIG. 3. FRAMING (LOOKING AFT) AND INNER SKIN PLATING; APRIL 14, 1915.

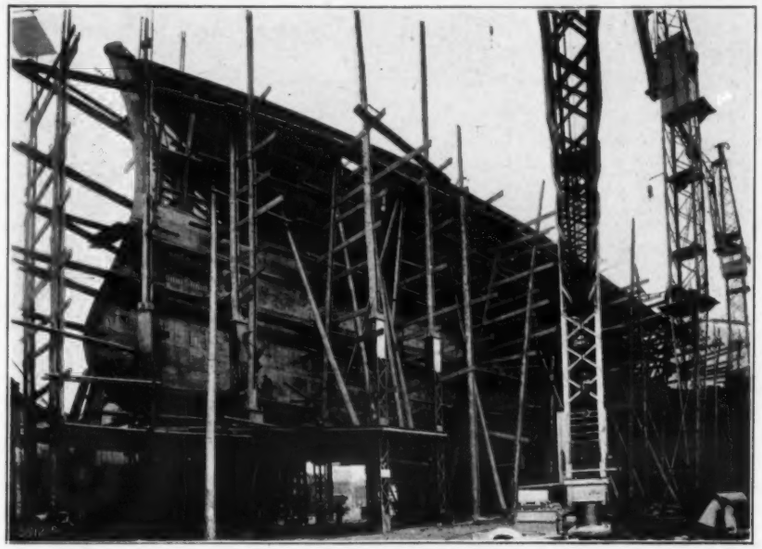


FIG. 5. STEM AND FORE PART PARTLY PLATED; OCTOBER 26, 1915.

FIG. 4. PROTECTIVE DECK PARTLY PLATED, AND BARBETTE STRUCTURE BEING FITTED; AUG. 18, 1915.

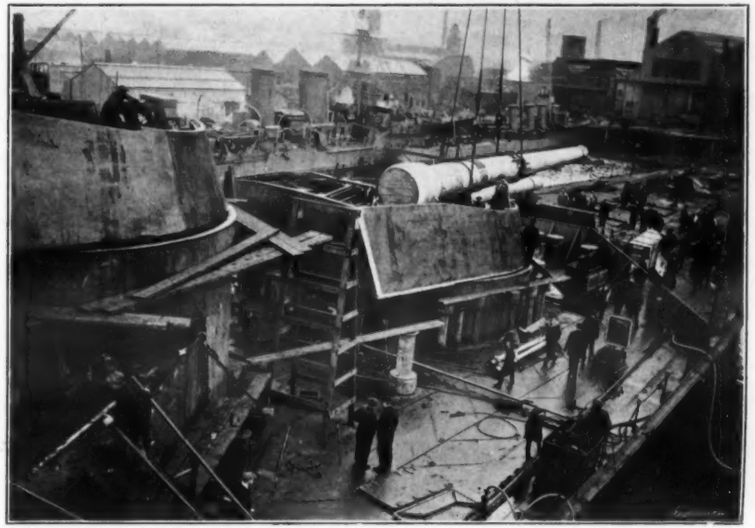
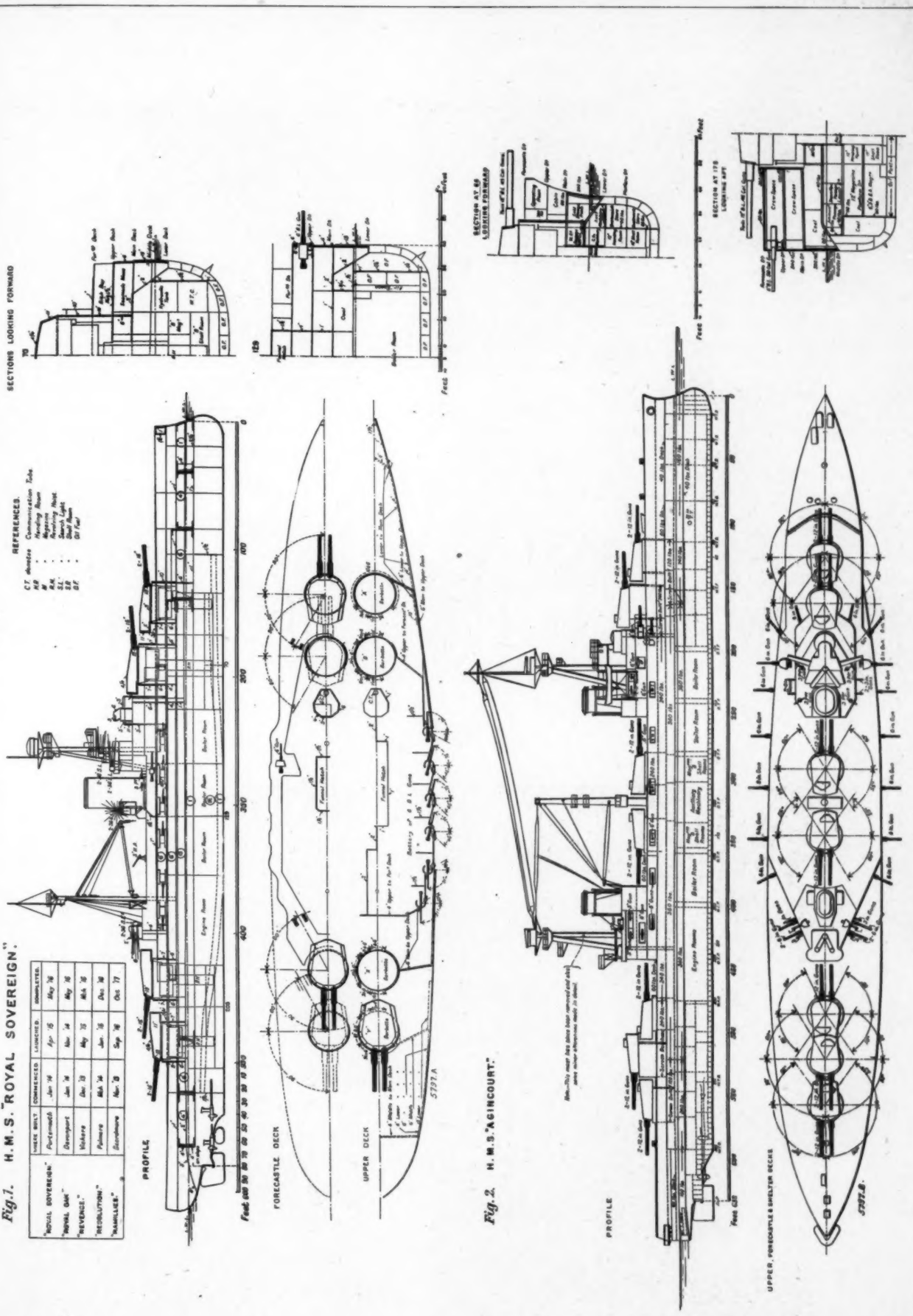


FIG. 6. 15-IN. GUN BEING SHIPPED IN FORWARD TURRET; APRIL 12, 1916.

(*To face page* 461.)

NAVAL CONSTRUCTION DURING THE WAR.

(*For Description, see Page 482.*)

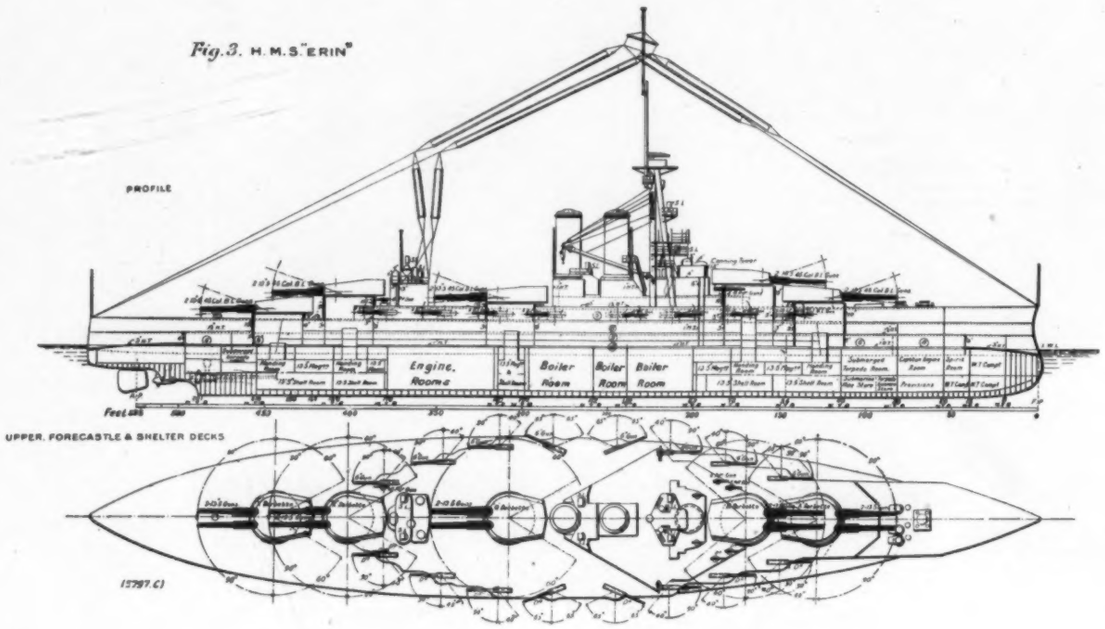

SECTIONS LOOKING FORWARD
REFERENCES.
PROFILE
FORECASTLE DECK
UPPER DECK
5731.A
Fig. 1. H.M.S. "ROYAL SOVEREIGN."
"ROYAL SOVEREIGN" Portsmouth Jan '14 Apr '15 May '16
"ROYAL OAK" Devonport Jan '14 Nov '14 May '16
"REVENGE." Vickers Dec '13 May '15 Aug '16
"RESOLUTION" Palmers Mch '14 Jan '15 Dec '16
"RAMILLIES" Swan Hunter Nov '13 Sep '16 Oct '17
SECTION AT 69 LOOKING FORWARD
SECTION AT 178 LOOKING AFT
PROFILE
UPPER, FORECASTLE & SHELTER DECKS
5731.B.
Fig. 2. H.M.S. "AGINCOURT."

(*To face page 482.*)

NAVAL CONSTRUCTION DURING THE WAR.

(*For Description, see Page* 482.)

Fig. 3. H.M.S. "ERIN"



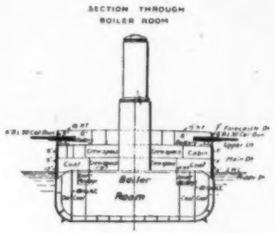
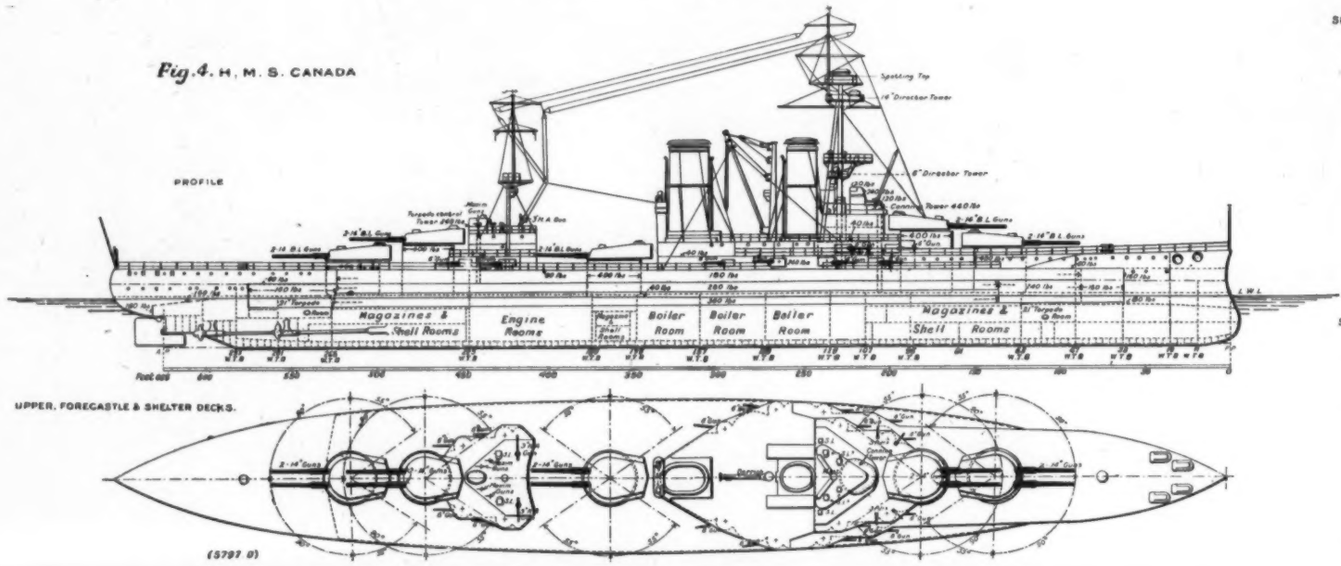
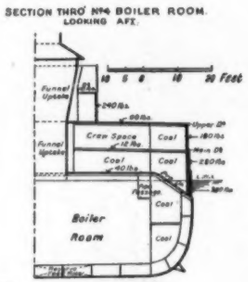


Fig. 4. H. M. S. CANADA





NAVAL CONSTRUCTION DURING THE WAR.

(*For Description, see Page* 482.)

Fig. 5. BATTLE CRUISERS "REPULSE" AND "RENOWN"

	REPULSE	RENOWN
COMMENCED BUILDING	25-1-1916	25-1-1915
LAUNCHED	8-1-1916	4-3-1916
DELIVERED	15-8-1916	20-9-1916

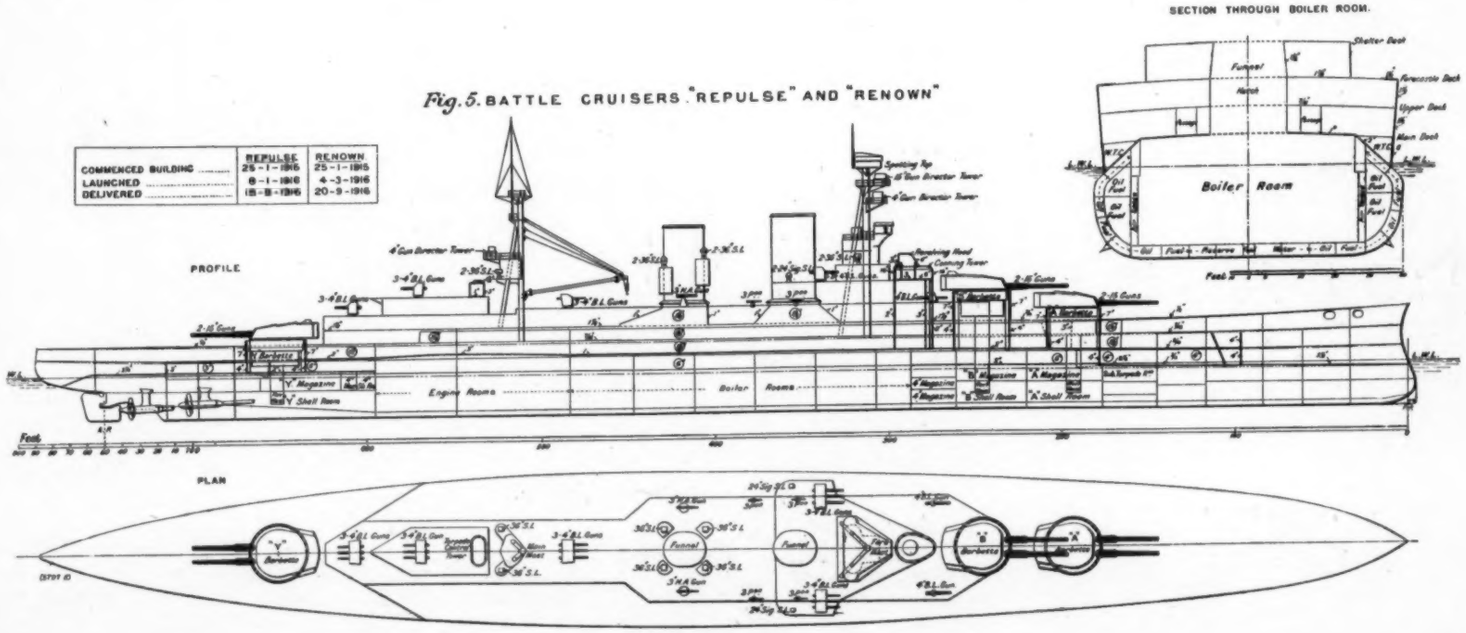
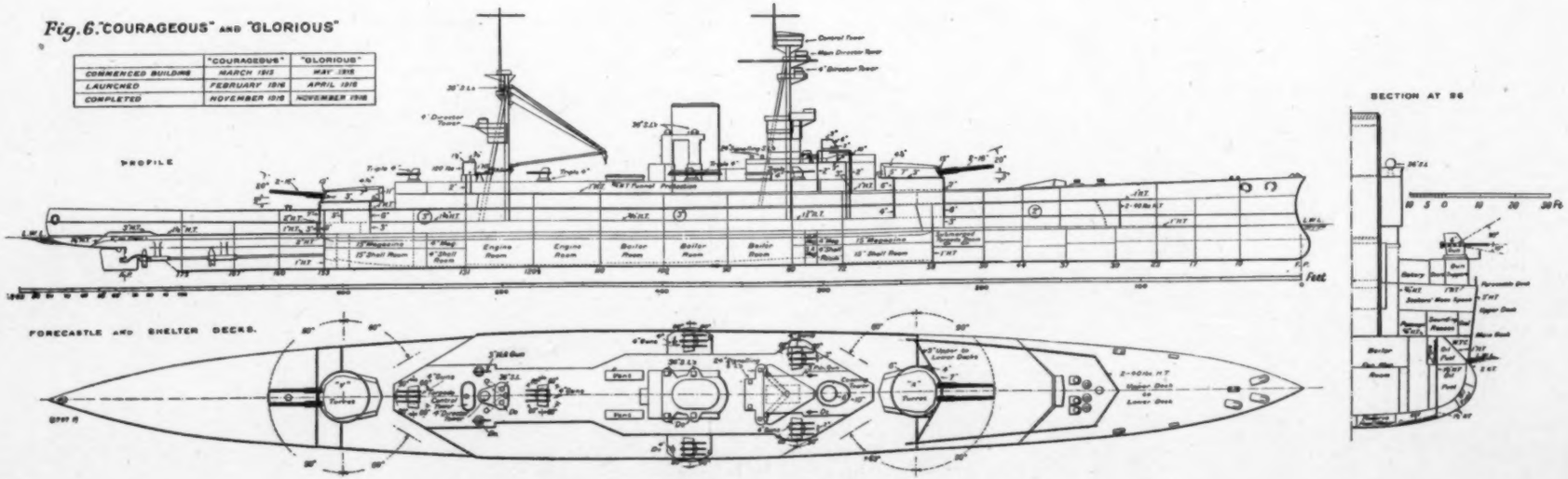


Fig. 6. "COURAGEOUS" AND "GLORIOUS"

	"COURAGEOUS"	"GLORIOUS"
COMMENCED BUILDING	MARCH 1915	MAY 1915
LAUNCHED	FEBRUARY 1916	APRIL 1916
COMPLETED	NOVEMBER 1916	NOVEMBER 1916



NAVAL CONSTRUCTION DURING THE WAR.

(For Description, see Page 482.)

Fig. 7. FURIOUS

Commenced building	June 1915
Launched	August 1916
Completed	July 1917

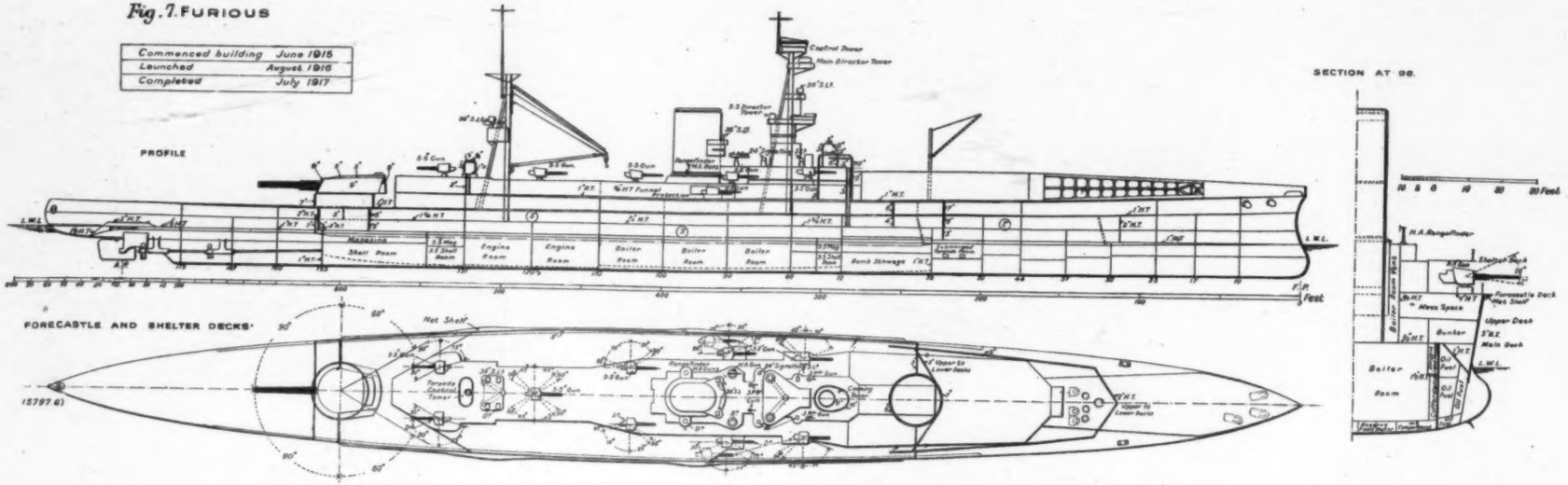
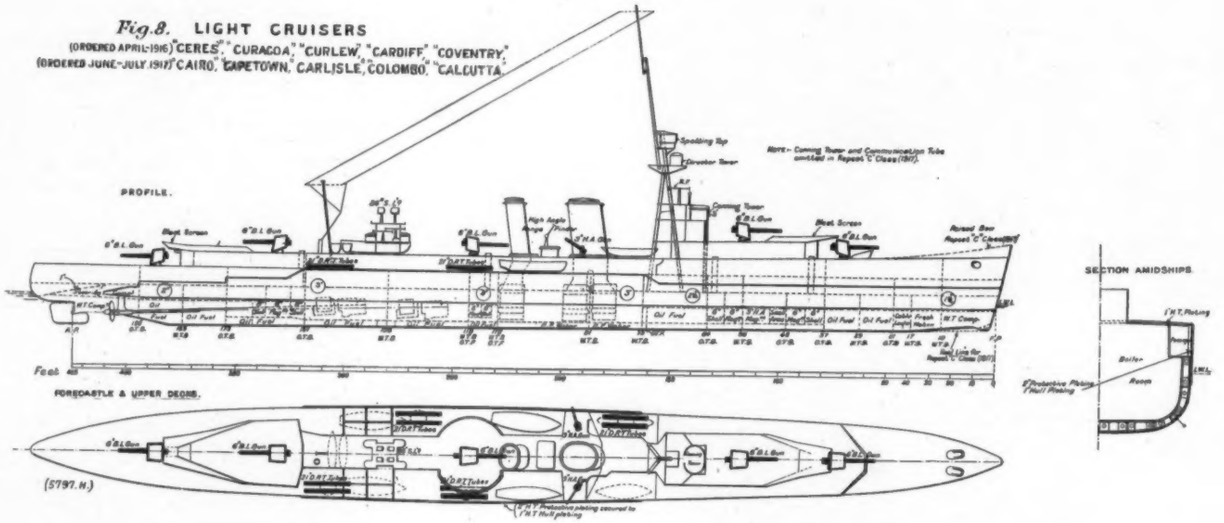


Fig. 8. LIGHT CRUISERS

(ORDERED APRIL-1916) "CERES," "CURAÇOA," "CURLEW," "CARDIFF," "COVENTRY."
(ORDERED JUNE-JULY 1917) "CAIRO," "CAPETOWN," "CARLISLE," "COLOMBO," "CALCUTTA."



(To face page 483.)

H.M. BATTLE CRUISER "REPULSE."

CONSTRUCTED BY MESSRS. JOHN BROWN AND CO., LIMITED, CLYDEBANK.

(*For Description, see Page* 461.)

Fig. 9. In Dock, Forward Turret Guns in Place; April 14, 1916.

Fig. 10. "Repulse," Destroyers, Monitor, and Submarine in Dock; July 15, 1916.

(*To face page* 462.)

TURBINE MACHINERY OF H.M.S. "REPULSE."

CONSTRUCTED BY MESSRS. JOHN BROWN AND CO., LIMITED, CLYDEBANK.

(*For Description, see Page* 461.)

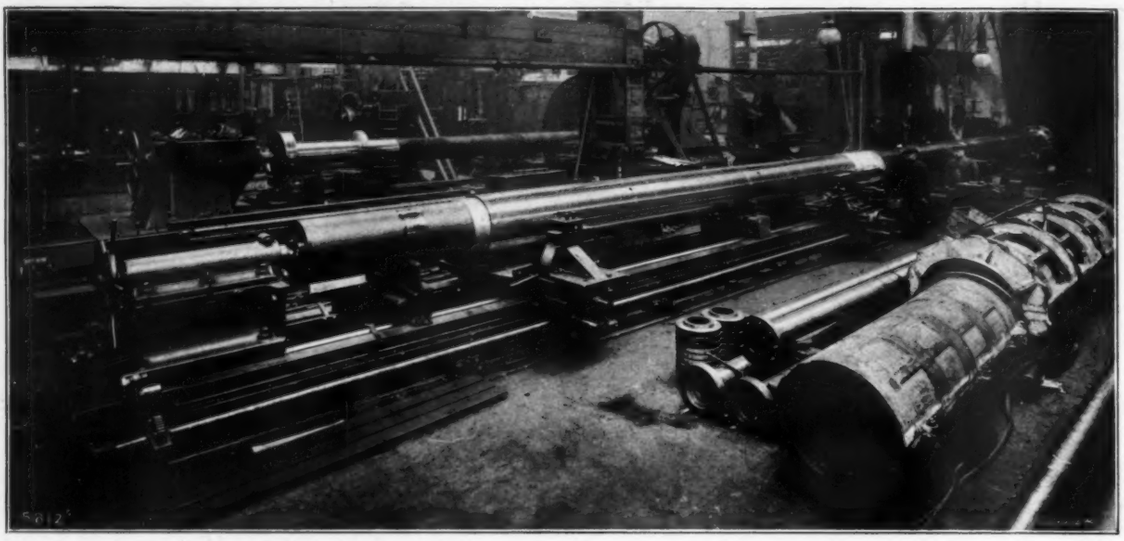


Fig. 11. Stern Tube Shaft in Lathe; Length 70 Ft. 3 In.

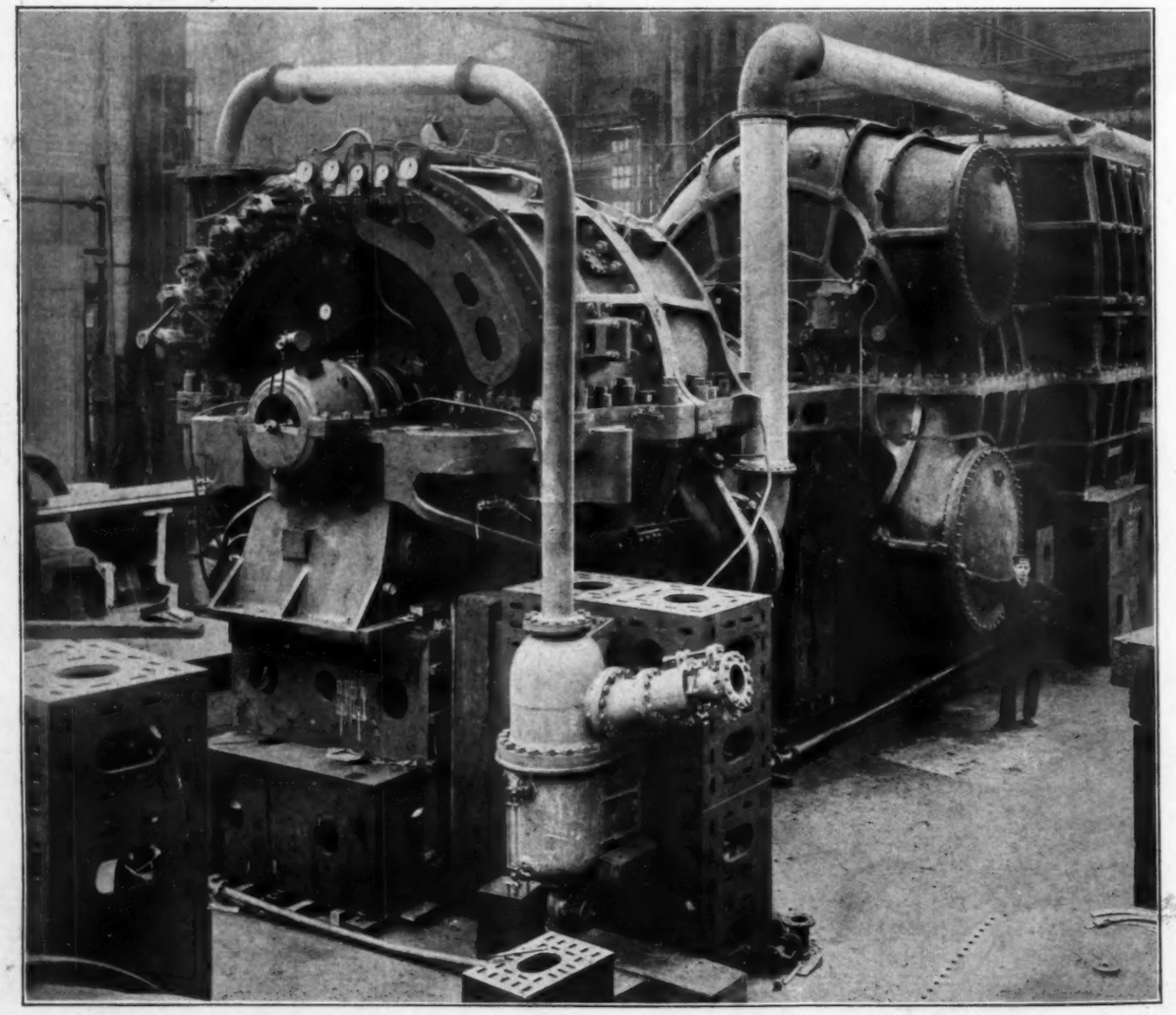


Fig. 12. High-Pressure and Low-Pressure Turbines being Prepared for Steam Balancing in the Shop.

(*To face page* 463.)

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TELEGRAPHIC ADDRESS } "ENGINEERING," WESTRAND, LONDON.

TELEPHONE NUMBERS—3663 and 8598 GERRARD.

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NOTICE TO NON-SUBSCRIBERS.

In view of the restrictions now imposed by the Government on the importation of paper and the consequent shortage of Supplies, Newsagents will not have copies for chance customers: therefore readers who wish to be sure of obtaining "ENGINEERING" each week should place an order for the Journal with a newsagent or bookstall clerk.

NOTICES OF MEETINGS.

Notices of Meetings to take place during the present and next week will be found on page 473.

ENGINEERING.

FRIDAY, APRIL 11, 1919.

WATER POWER IN BRITAIN.

THE relative backwardness of this country in the development and application of natural water power is due firstly to the fact that we really have not got very much to develop; secondly to the circumstance that except in very favourable situations the natural water power has been unable to compete with artificial steam power; and thirdly to the enormous difficulty of getting Parliamentary sanction for the carrying out of development schemes and the cost of dealing with local interests and opposition. The industrial situation brought about by the war has, however, re-directed attention to this question of the utilisation of natural sources of power, and it may be well to consider the causes of comparative stagnation in the past, in the light of the circumstances in which we now find ourselves.

Although the available natural water powers of the islands are small as compared with those of many other countries, they are not negligible as, apart from any other evidence, is shown by what has been done at Kinlochleven and Foyers and in North Wales. What water power is available in other districts has, we think, not up to the present been thoroughly investigated; at all events, with such completeness as would enable a just estimate to be formed of its economic value. The Royal Commission on Coal Supplies reported in 1905 that the total saving of coal which might be effected by the use of all our available water power would be only about 1,200,000 tons a year. This figure may be compared with one of something over 7,000,000 tons, which represents the present coal consumption of all steam power stations supplying electric power for public use, and driving electric railways and tramways. Private power plants are not included. This figure, given by the Commission on Coal Supplies, is however entirely upset by figures given in the interim report of the Water-Power Resources Committee, just published. This Committee was appointed in June of last year and it is undertaking a complete survey of water power possibilities. The figures it publishes must of course carry more weight than those, more or less incidentally, given by a committee not dealing specifically with the subject under discussion. The Interim Report attempts no estimate of the total power available, as the surveys are not yet completed, but it states that so far from the total coal saving only amounting to 1,200,000 tons per annum, the power from nine potential schemes alone, in Scotland, would equal the result obtainable from a coal consumption of 1,850,000 tons a year. We will deal with some of the details of this interim report later, but for the moment may take it that the Committee show that there are still important water-powers available for development.

In our first paragraph we said that the second reason for the backwardness of this country in the application of water power was that such power has been in but few cases able to compete economically with steam power. This is a condition in which the new industrial conditions in which we find ourselves may well breed a change. The immediate and obvious consideration is the price of coal. Although the capital cost of a hydro-electric station will now be higher than it would have been in 1905, so also will the capital cost of a steam station, and it is quite possible that any difference in the extent of increase in cost of the two plants will be in favour of the hydraulic installation. In any case the steam station will have to use a fuel which has increased in cost by more than 100 per cent., while other running charges will have increased to an equal extent with those of a hydro-electric plant. This question of coal cost alone is likely to have put many water-power schemes in a position in which they can present a much more favourable commercial case than would have been possible ten years ago.

Consideration of the third cause hampering the development of natural water powers in the past—Parliamentary and similar difficulties—brings us at once to the doorstep of the Ministry of Ways and Communications. We are glad that general electric supply has been dropped from the Bill, but with a Minister of Transport desirous of using electric traction more extensively than now, a very different state of affairs would exist in the future from what existed in the past in connection with the obtaining of authority for the utilisation of water powers. It is not too much to say that of the causes hampering hydro-electric development in the past this third one on our list has been the most potent. The mere difficulties in the way of obtaining rights-of-way for overhead lines have been almost enough in themselves to deter any commercial corporation from meddling with the subject of hydro-electric development. When on top of this there has been the landowner to buy off and the various Parliamentary oppositions engendered by the local interest, municipalities, the æsthetic party and the rest, it is a wonder that so much has been done rather than so little. It is also pertinent to remember that overhead lines, which are in many cases an essential part of hydro-electric development, were looked upon with very little favour by the Board of Trade not very many years ago.

It is, of course, impossible to say how the activities and methods of the Ministry of Ways and Communications will ultimately develop, but if half of the freedom and overriding authority, with which it is apparently proposed to endow that Ministry, germinate into actual fact, then water-power schemes may be carried out which it would have been folly for any private body to attempt to touch under the old *regime*. There is not the slightest doubt that given proper authority and freedom from necessity for buying off interested and arbitrary opposition, many commercially sound hydro-electric possibilities might be found in these islands. This is not to say, however, that it will pay to stick a turbine and dynamo at the foot of any and every waterfall, even if steam coal is 25*s.* a ton. We realise that much that has been published about this matter is uninstructed chatter, but none the less there is a dangerous idea abroad at present that the road out of our present financial morass lies over an amazing array of public works of various kinds, all constructed and operated by the Government and all apparently undertaken without reference to their economic justification. Confining ourselves to our present subject, one can but hope that no hydro-electric scheme will be undertaken with public money until it has been examined by someone with rather a harder head than either a Socialistic visionary or an enthusiastic reporter.

In connection with the question of authority to develop and the difficulties encountered owing to the activities both of private and statutory opposition, the report to which we have referred suggests that all water powers above a certain size should be secured by the State and that the control of the whole of any watershed should be vested in one authority in place of the various bodies now representing fishery, agriculture, drainage, water supply, river-pollution and the many and other interests which of necessity arise. The Committee quote Lord Elgin's Commission on Salmon Fisheries, which reported in 1902 in favour of setting up Watershed Boards under a Supreme Rivers Authority.

Turning to the specific matter of the report the committee, as we have said, state that nine water-power sources in Scotland which have already been surveyed would, if developed, represent a saving of 1,850,000 tons of coal a year, calculated from present average practice in electric power stations. The nine plants would be capable of developing a

continuous electrical horse-power of 183,500, corresponding to an output of 1,200,000,000 Board of Trade units a year. The estimated total capital cost for the nine projects is stated to be about 7,000,000*l.* This, however, is an estimate based on pre-war prices and the report suggests that the sum should now be increased by 50 per cent. The average cost per electrical horse-power at the power-house, taken over the whole three schemes, is 38·5*l.*, still at pre-war values. The largest of the proposed schemes is one involving developments at Lochs Ericht, Laidon, Rannoch and Tummel, in the north part of Perthshire. This scheme is estimated to produce a continuous electrical horse-power of 42,000 and to cost 1,580,000*l.*, or 37·6*l.* per electrical horse-power (still pre-war costs). The centre of this proposed development would be within some 60 miles of Dundee, Perth and Stirling. The second largest scheme concerns Lochs Laggan and Treig, in Inverness, some 30 miles to the west of the Loch Rannoch scheme. It is estimated to produce 38,000 electrical horse-power at a cost of 45·8*l.* per horse-power. The other proposals range downward in capacity to one of 7,200 electrical horse-power at Loch Monar, in Cromarty. The cheapest scheme is one requiring only a capital expenditure of 17*l.* per electrical horse-power, situated at the Kilmorach Falls and estimated to have a capacity of 9,500 h.p. In connection with these estimated capital costs some figures which were given in a paper read by Professor A. H. Gibson before the Royal Society of Arts on the 26th ult. may be quoted. Professor Gibson stated that a recent analysis of 70 representative hydro-electric stations in Canada, aggregating 746,000 h.p., showed an average construction cost of 14*l.* 12*s.* per brake horse-power. This figure, however, does not include cost of land, nor cost of transmission. In New Zealand the cost of a number of schemes aggregating 3,800,000 h.p. averaged 31*l.* per horse-power, including transmission.

It will be quite clear from a brief consideration of the subject of water-power in Britain, quite apart from any details that we have quoted, that if an attempt is to be made to utilise a considerable part of the possible sources, then a large number of the stations will be remote from any important centres of population. The interim report recognises this, and suggests the establishment of new electro-metallurgical and electro-chemical industries to absorb the power locally. This sort of thing can, of course, be done from an engineering point of view, and there is no doubt at all but that flourishing carbide or calcium-cyanamide plants in remote parts of Scotland would react favourably on the districts concerned, leading, for instance, to increased agricultural and dairy farming prosperity. If this type of industry is to be established successfully, however, it must be operated on a basis which can bring the costs of production to somewhat the same order of magnitude as is reached by similar plants in cheaper countries, such as Sweden and Iceland. The Committee make no suggestions about the ownership or establishment of such plants, but clearly it will not necessarily follow that a British carbide industry can be developed merely by building a number of hydro-electric stations in Scotland with public money.

In many of the schemes they are putting forward, the Water-Power Committee are, of course, proposing that the power should be transmitted to existing centres of population and manufacture. The nine projects we have mentioned, for instance, are stated to be capable of delivering at least 1,000,000,000 Board of Trade units a year within a radius of 80 miles to 85 miles, and supplying Glasgow, the Clyde Valley, Edinburgh and district, Aberdeen and Dundee. When it is stated that the total Board of Trade units generated in the year 1917–18 by all the steam power stations in Scotland, including public utility undertakings, but excluding private plants, amounted to about 537,000,000 Board of Trade units, the importance of the proposed water-power stations will be manifest. They would have, it will be seen, nearly twice the capacity of the existing steam stations. The transmission of electric power for 85 miles is, of course, an engineering problem which has been successfully dealt with in several parts of the world; but whether it can be carried out at such a cost as to supply the current to consumers at a price which is commercially advantageous, is another matter. Amongst other things it is possible that the humid climate of Scotland might introduce special difficulties, but of course there is no reason to suppose that these would not be more or less overcome.

Other schemes mentioned in the report, but of which no detailed information is yet available, are situated in the Lake District, Devon, Cornwall and North Wales. A project in the last-named area is stated to be capable of developing 4,400 continuous horse-power at an estimated capital cost of 41·8*l.* per horse-power. In connection with this project it may be of interest to mention that the capacity of the existing hydro-electric station of the North Wales Power and Traction Company is 6,000 k.w. The report also mentions that a scheme for the utilisation of the tides of the River Severn is under examination. It may be remembered that the Chester Corporation has at the present time a small hydro-electric station which is operated from the tidal flow of the River Dee. There are three turbines having a total capacity of about 600 h.p. The station has been very successful. In the five years ending October 20 last this hydro-electric station generated 8,622,015 units at a cost of 5,370*l.*, as compared with the Corporation steam station, which in the same period generated 9,625,819 units at a cost of 25,957*l.* The hydro-electric station is estimated to be saving from 3,000 tons to 4,000 tons of coal a year. The Worcester Corporation also has a somewhat similar small hydro-electric station. There is little doubt but, as the report says, that there are numerous small water powers in the country ranging from, say, 100 h.p. to 2,000 h.p., which are at present running to waste and which might be developed to serve local requirements, or to feed into a general electrical transmission network.

YOUTH AND AGE.

THE two outstanding human discoveries of the war have been the intrinsic value of youth and age. In normal times youth finds it difficult to assume responsibility and age to avoid supersession. Immaturity and senility are both far too readily assumed. The youth just finished training finds his appearance unconvincing to a prospective employer, and grey hairs are regarded quite as dubiously. Was there not a learned professor who formulated the thesis that a man's best work was all done before he was forty?

Age, undoubtedly, brings its disabilities, but it is an outstanding fact that the last activity to ripen, is also the last to decay; intelligence and intellect being the last to develop are also the last to fail. Brain power persists almost to the end of the longest life, provided it is continuously used and not allowed to atrophy for want of exercise. On the other hand, youth finds it difficult to win the confidence of a more mature generation, and for this reason is shorn of opportunity and thereby defrauded of the chance to develop.

The war afforded unique opportunities both to the elderly and the immature. Men relegated by convention to a life of placid retirement, in which to enjoy well-earned leisure and so prolong existence on the fruits of their earlier activity, found a new stimulus in national need, regained a foothold in the world of affairs, and in many instances shamed those in the noon of mid-career. Responsibility can come too late, as retirement can come too early. The best human material welcomes early service and opportunity, and relinquishes its burden with regret.

One of the outstanding advantages of birth, influence and position is the opportunity they afford at an early age to shoulder responsibility. Granted the right material great development is contingent upon such assumption at the right age. Those destitute of such natural advantages have to take a longer road and to travel further; they do not get their chance until by sheer ability they seize a position, and then perhaps, for obvious reasons, it is obtained too late.

To a very real extent knowledge is the privilege of youth; its acquisition is then more easy in terms of mental disturbance, but experience is requisite to guide its application. Under proper conditions judgment should come with maturity and deepen and widen the limits of active life. Somewhere between the impetuosity for which youth is famous, and the extreme conservatism which is held to distinguish age, lies the golden mean of enterprise tempered with discretion.

Apart from direct military services, which needs must demand its human material at the most resilient age when physical endurance is greatest, the recent unexampled extension in emergency gave to trained youth unparalleled opportunity, and offered it responsibilities to shoulder which normally would fall to more mature years. The ideal combination may be youth at the prow and age at the helm, but it has at all events been made apparent that great faculties develop earlier and continue later than has hitherto been supposed.

In such a period as we have recently passed through, liberation of every type of activity has been marked. It was necessary to get every ounce out of the national team and scope was afforded without stint. In some senses the war has been the clear dividing line between a past now so remote as to be historic, and a future intensified and accelerated by recent events. Both youth and age have contributed much more than their normal share in emergency, and this latent reserve is now apparent.

Whencesoever it comes, the new spirit whose travail is obvious in every direction—the mutual interaction which has produced the present—owes some part of its production to youthful enterprise and part again to riper knowledge. Closed doors have been wrenched open by the violent hands of youth, and the national stage has seen both debut and recall. In view of the recent prolonged test, the ruling which disallows the advance of youth and is too ready to assume that activity necessarily ceases prematurely, has been falsified. It never was true, and the convention which was responsible is another misconception to be relegated to oblivion.

The instantaneous poise of any age is not the product of a single generation, at least three interact mutually. Youth which adventures, maturity which confirms, age which withholds. Impatience is curbed by understanding, real advance is gained by impatience held in leash by the control of riper years.

It is probably true that there are seven ages of man, but modern conditions for all their stress and hustle leave a man at the age he feels. There are some who never grow up and some who never grow feeble. At all events the war has proved, if proof were wanting, that the real spell of active and responsible endeavour is very much longer than was formerly held to be the case.

SPECTRUM ANALYSIS AND ATOMIC STRUCTURE.

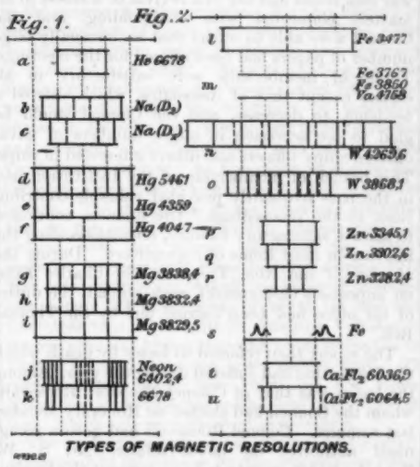
IN his fourth lecture on "Spectrum Analysis and its Application to Atomic Structure," delivered at the Royal Institution on Saturday, March 29, Sir J. J. Thomson, O.M., P.R.S., continued his discussion of the various series that could be distinguished in the lines of spectra.

The model, of which he would make use in his explanations, Sir Joseph said, was again that of the hydrogen atom. The one electron might occupy different equilibrium positions within the atom. Supposing in one atom it were near the boundary of the atom, the place at which the magnetic force vanished; in another atom it might be a little nearer to the centre, in a third nearer still, and the possible positions would become the more crowded, the more we approached the centre. The frequency of the vibrations would be determined by the magnetic force. The magnetic force was assumed to vary as $(a^2 - r_1^2)$, where a was the radius of the atom and r_1 the distance of the electron from the centre. The frequency of the vibration would thus vary as $N(a^2 - r_1^2)$, as previously explained. For the electron at the smaller distance r_2 the frequency would vary as $N(a^2 - r_2^2)$, for the electron at distance r_3, as $N(a^2 - r_3^2)$, and so on. As we approached the centre, the r became smaller and smaller, until finally, for $r = 0$, the frequency would simply vary as Na^2. That condition represented

the limit of that series of lines. Now let the boundary shift from one position of equilibrium to another further inward, previously occupied by any electron. In the formula for the frequency we should have to substitute r_1 for what was a, and the formula for the first line would hence turn into $N(r_1^2 - r_2^2)$; the other lines would similarly be represented by $N(r_1^2 - r_3^2)$ and so on, and the limit value towards which this series converged would be given by $N r_1^2$. The connection now between the principal series and the first subordinate series, the sharp series, was given by the law of Rydberg-Schuster, viz.: The frequency of the slowest line in the principal series was equal to the difference between the limit in frequency of the principal series and that limit in the sharp series, represented respectively by $N a^2$ and $N r_1^2$. The difference of these was $N(a^2 - r_1^2)$, which, as we had seen, was the expression for the first line in the principal series. The model suggested would therefore lead to a formula of the Rydberg-Schuster type.

Turning to the distinctive properties of the various series, Sir Joseph remarked that it would be like looking for a needle in a haystack to attempt to pick out the lines of special series without some kind of guide. What we could do was to try to find lines probably of the same character, and to separate these lines from others. The characteristics shown by lines of the same series were almost invariably common to all the lines of that series, and by applying suitable physical tests to the lines the task of picking out the lines of certain series was extraordinarily simplified. There were several such tests available. One of these was the relative ease with which a line could be excited, or, so to say, the feebleness of the electric force sufficient to produce the lines. By adjusting the electric circuit of an arc the spark passing between the electrodes could be changed into a flame. For his demonstration, Professor Thomson used an arc with two horizontal carbon electrodes in alignment. When an image of that arc flame was thrown on the vertical slit of a spectroscope, light would reach the slit from particles within the horizontal plane of the electrodes as well as from other parts of the flame. If the source of light were along the line joining the terminals, the corresponding lines in the spectrum would merely be dots or short lines; if the light came from gas particles further away, the spectrum should show higher lines, longer in the vertical direction. Now we actually observed short and long lines in some spectra, and Lockyer had proposed this long and short-line method for selecting lines belonging to the principal series which was made up of long lines when the spectrum was produced in the way described.

Another characteristic property of great service had been discovered at the Johns Hopkins University of Baltimore. When the spectrum of a gas at great pressure was observed, some lines would be shifted from the positions they occupied when the gas was at normal pressure, and these lines were found to belong to the same series, when they were submitted to numerical calculations. The effect of the magnetic field on a spectrum supplied another and the most complete way of distinguishing between different series. Investigating the various properties of magnetic fields, Faraday discovered that the plane of polarisation was rotated by the magnetic field, and he looked for further effects. With more perfect modern apparatus Zeeman later observed that in intense magnetic fields some lines were resolved into a number of components. The effect depended upon the direction in which the observer looked, along the lines of force or at right angles to them. The slides, Figs. 1 and 2, which Sir Joseph exhibited illustrated the transversal effect; the light was produced between the poles of the electromagnet, and the observer looked in the direction at right angles to the lines of force crossing between the two poles. Then spectrum lines which had originally been sharp and single became broadened and actually split up in varied extraordinary ways (Figs. 1 and 2). Thus instead of one line we might see a triplet, two new lines appearing, one to the right, the other to the left of the original line; the distance between the components depended upon the strength of the field, but the effects were extraordinarily varied. Each of the components had its own period of vibration. Helium gave the simple triplet described. The sodium D line was not only shown to be double—which had already been known—and to consist of two components D_1 and D_2, close to one another; but the line D_1 could be resolved into two components, and the line D_2 into four, so that we had altogether six lines instead of the one D line. There was no doubt that D_1 and D_2 belonged to different series, and Wood had indeed succeeded in exciting the one D line without the other. More complex separations were observed with mercury, tungsten, zinc, iron and other elements, and the Zeeman effect was very variable. But Preston had proved that lines belonging to the same series underwent the same resolution, all being split into three or six lines, &c.



TYPES OF MAGNETIC RESOLUTIONS.

The direct demonstration of the Zeeman effect to an audience was a very difficult experiment, but the fact that there was an effect, Sir Joseph said, could be demonstrated in the following way. A small sodium flame B (Fig. 3), a Bunsen burner, was burning between the horizontal poles of a

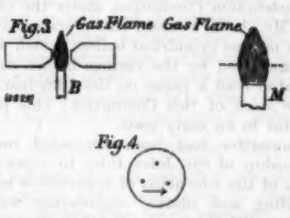


Fig.4.

powerful electromagnet; in front of this flame was placed a bigger Méker burner, M, also containing sodium chloride vapour, this vapour serving as absorbent for the sodium light emitted by the first flame. The big flame was purposely kept cool, and to attain this, the salt was placed on the wire gauze immediately over the mouth of the Méker burner, while another piece of coarse wire gauze was fixed an inch or two higher up. Further in front of the big flame was a lens and, a few yards further off, a screen. The cool vapour absorbed so much of the faint light, given out by the small sodium flame, that the screen appeared dark. When, however, the electromagnet was excited, a slight brightness was seen in the spot where the D line should have appeared. The reason was that the sodium light emitted by the small burner was changed by the magnetic field and was no longer the ordinary sodium light which the vapour would completely absorb owing to its intense selective absorption; hence a little light was able to pass through the vapour cloud.

Some of the lines in his Zeeman diagram, Sir Joseph continued, were resolved into as many as 16 lines, and the resolution of one line into so many components proved that the original line could not have been produced by one single atom. For we might split up a line into three, since there were three directions in which an electron could move; but we could not obtain more than three lines in this way from one particular electron. We could easily see, however, that two or more electrons though placed symmetrically in the atom would behave differently when under the influence of a magnetic force. Supposing three electrons were arranged at the corners of an equilateral triangle in the centre of the atom; they would all vibrate in the same way, but the external field, represented by the arrow in the diagram (Fig. 4) would influence the different electrons differently. In this way again the Zeeman effect would enable us to differentiate between different series. There was still another very useful guide for analysing complex spectra for series. Most spectrum lines appeared in doublets or triplets, the members of the group being close together; the observation of doublets had in fact suggested the existence of series to Dewar and Liveing in the early days. We should expect such a grouping with an asymmetrical arrangement of the electrons within the atom.

In the subordinate series, the sharp and the diffuse series, the frequency difference between two members of a doublet was constant. In the principal series, however, the members of a doublet approached one another more and more as we traced them into the violet and beyond, where they finally almost coincided. By determining the frequency differences between the members of the doublets and triplets, we could thus assign the lines to the various series. That the two members of the doublet in sodium belonged to different series had already been mentioned. Most of the early work on series was done on alkali metals, and the name "principal series" was adopted for lines in these spectra which were absorbed by the atoms or molecules existing in the cold vapours of the alkali metals.

The investigation of the absorption spectra of other metals, mercury and cadmium, for instance, showed these spectra to be simple, so far as the investigation went; but the principal series of these two metals had not been worked out yet. Certain reversible lines had however been fixed; their wave-lengths were in Angström units: mercury 2536, 2338, 1849; cadmium 2288, 3260; zinc, 2139, 2075. These lines were presumably the natural vibrations of the cold vapours of these metals, and they were excited by kathode rays passing through them, this being one of the simplest methods.

Under certain conditions, at present extensively studied by J. C. McLennan, the excitement of vapours by kathode rays gave a spectrum of only one line, and this was one of the lines shown in the absorption spectrum. The consideration of this method of excitation and of its effect, Sir Joseph stated, would lead him to the quantum theory. He would first, however, demonstrate that the luminosity excited by bombarding various substances with kathode or anode rays changed with the conditions of the experiments and the speed and energy of the bombarding particles. Various minerals glowed in different colours when bombarded. At the bottom of one discharge bulb was placed a piece of aluminium foil covered with a thin layer of fused lithium chloride; the one electrode of the bulb was a disc, the other a tube; bombarded by (high-speed) kathode rays the chloride glowed in bright blue light; when it was bombarded by the much slower heavy anode rays, the colour changed into bright red. This was further demonstrated by placing a spherical glass bulb containing some rarified gas inside a cylindrical coil of wire, so that the gas itself acted as secondary when the primary discharge was sent through the coil. In the centre of the bulb, where the field of electric force was weak, the glow was pink; near the glass walls, where the field was stronger, the glow appeared green.

To introduce the quantum theory, Sir Joseph continued, he would select a case furnishing, perhaps, the strongest evidence in favour of the theory. Let light of a certain wave-length fall on a metal surface; negative electrons would be ejected from that surface at a speed which could be measured; as long as the exciting wave-length remained constant, the speed of ejection would likewise be found to remain constant. We might alter the intensity of the light from dullness to great brightness by going

quite close up to it, *e.g.*, that would have no effect at all upon the speed. A faint blue light, barely visible at great distance, would eject particles at a certain speed; but it would be useless to try intense red light in order to get up such a high speed, even if we put far more energy into that red light than into the blue light. Roughly speaking the speed of the particles was proportional to the frequency of the light, and the energy in the particles depended upon the character, but not upon the intensity of the light. Let us assume that the energy of the ejected particles came from the light. The quantum theory then explained this peculiarity, that the amount of energy in the ejected particles depended only on the character, the frequency, of the light, and not upon its intensity, in the following way: the transformation of the energy of light into another form of energy, such as that possessed by the ejected particles, could only take place by certain amounts, in definite units. We could not exchange less than a certain amount of blue light into another kind of energy; the blue light had no "small change," and there was a simple relation between the amount of energy exchanged and the frequency of the light. That relation was: energy $\omega = h\nu$, where ν was the frequency and h Planck's universal constant. The law said that the transformation of light energy into other energy took place, not continuously, but only in definite units or steps. Any transformation represented a multiple of a certain unit; all transactions had to be settled in sovereigns, *e.g.*, not in smaller coins. The same argument held for the reverse transformation of energy back into light. The character of the light depended upon the amount of energy transformed; little energy would produce red light of low frequency, much energy would give rise to blue light of high frequency, and the relation was again: $\omega = h\nu$.

This theory had undoubtedly rendered most valuable service to the elucidation of the problems of spectroscopy, specific heat at low temperature and other problems. To a certain extent it was an empirical relation. The law did not enable us to form a physical conception of what was going on when the energy was being transformed; that was a mystery. It was very difficult for many people to give up the principle of continuity. In the case considered there was a region—the transformation of the energy into some other form—about which we knew nothing. It was as if we were travelling from London to Edinburgh in a sleeping car; we found ourselves in Scotland next morning, but could not say anything about the country we had travelled through. As regards the energy of light changed into the energy of the moving particle, we knew the result, but nothing more.

That did not prevent the quantum law, however, from being of immense service. The second law of thermodynamics might likewise be described as empirical. It was suggested by common observation, but not really suggested by dynamical considerations. Lord Kelvin had, to the end of his life, congratulated himself upon having always urged that the second law was empirical and could not be applied indiscriminately to all problems; he would not apply it, for instance, when radio-activity came up. Maxwell had said that if we would imagine bodies small enough to manipulate atoms individually—Maxwell's sorting demons—to open the door to particles moving at fast speeds and to shut it to slow particles, we should be able to separate the fast and the slow particles into separate categories, and thus to render the second law invalid. We knew now that this law was a statistical law, true only as an average of an immense number of transactions, but not necessarily applicable to any individual case. The trouble about all empirical laws was that we did not understand their limitations unless we knew what was going on. That was so with the quandum theory. Suppose a unit of light were falling on an atom; part of the light was scattered; was it all scattered? If it could not all be re-emitted in the same direction, was none re-emitted in that direction? The presumption was that the quantum law did not hold in many cases; in others it gave results in close agreement with experience.

THE INSTITUTION OF NAVAL ARCHITECTS.

THE annual meetings of the Institution of Naval Architects were opened in the Hall of the Royal Society of Arts at 11 a.m. on the morning of the 9th inst. In the absence, owing to illness, of the President, the Earl of Durham, the meeting was presided over by the Marquis of Bristol, Past-President. There was a large attendance.

ANNUAL REPORT.

The first matter dealt with was the reading of the annual report by the Secretary. The report began by pointing out that, notwithstanding the disorganisation due to the war, it was a source of satisfaction that the Annual Meetings had been carried on without interruption. The cessation of war conditions had led to a revival of interest in all matters connected with shipbuilding, and the Council were able to report that an unusually large number of papers had been offered for the meetings. Totals of membership were satisfactory in all classes except that of Associates, which showed a tendency to decrease, and the Council would be glad to see accession in larger numbers of naval officers, ships' officers and others interested in ships. This branch of membership of the Institution had in the past frequently provided valuable contributions to the proceedings. The finances continued to show a satisfactory balance, notwithstanding the increase in most items of expenditure. During the absence of the Hon. Treasurer, Sir Charles Ellis, on important Government work abroad, the duties of his office had been carried out by Sir Thomas Bell.

The report then referred to losses by death which the Institution had suffered during the year. Among the losses was that of Colonel Theodore Roosevelt, whom the Council had elected an Honorary Member last summer. Colonel Roosevelt had been a recognised authority on naval affairs. Mr. S. W. Barnaby had been selected to represent the Institution on the Corrosion Committee of the Institute of Metals in place of Sir J. E. Thornycroft, resigned. The report also announced that Sir John Biles having served for upwards of twenty years on the Council, had been elected an Honorary Vice-President. The British Marine Engineering Design and Construction Committee, under the chairmanship of Mr. A. E. Seaton, had prepared a code of rules for marine cylindrical boilers, which were now being considered by the various bodies concerned. (Mr. Seaton read a paper on the 10th inst. dealing with the work of this Committee; this paper we shall print in an early issue.

A Committee had been appointed under the chairmanship of Sir John Biles to report on the question of the education of apprentices in private shipbuilding and marine engineering works. In connection with this matter the Council were pleased to report the offer of two scholarships in Naval Architecture of 150*l.* a year for three years, one from Messrs. Cammell Laird, and one from the Fairfield Shipbuilding Company. Also of one in marine engineering of the annual value of 150*l.*, from the Parsons Marine Steam Turbine Company. Messrs. John Brown had promised 1,000*l.* towards a 10,000*l.* Scholarship Fund, on condition that the remaining 9,000*l.* was raised. The Institution of Naval Architects Scholarship for 1918 had been awarded to Mr. H. W. Nicholls, of Chatham Dockyard, and the Earl of Durham's prize for 1918 to Mr. P. H. Knapman, of Devonport Dockyard. The annual Gold Medal of the Institution had been awarded to Mr. A. M. Robb for his paper on "The Shearing Force and Bending Moment Acting on the Structure of a Ship," and the Premium to Major M. Denny for his paper on "The Possibilities of Reinforced Concrete as a Material for Ship Construction." The result of the referendum of last August on the question of the admission of women to the Institution had been in favour of the admission.

BALLOT FOR MEMBERS OF THE COUNCIL.

The result of the ballot for new members of Council was then read as follows:—Vice-President, Mr. A. E. Seaton. Members of Council: Mr. R. R. Bevis, Mr. James Brown, Mr. P. T. Caird, Mr. A. E. Doxford, Mr. W. H. Gard, Mr. P. A. Hillhouse, Engineer-Captain J. McLaurin, Mr. F. J. Stephen, Mr. R. J. Walker. Associate Members of Council: Sir William Beardmore, Mr. W. L. Hichens, Vice-Admiral Sir Roger Keyes.

The list of new members and associate members was then read, and the Institution Premium presented to Major Denny. Mr. A. M. Robb was not present to receive the Gold Medal.

The acting President, the Marquis of Bristol, then delivered his address.

INAUGURAL ADDRESS.

The Marquis of Bristol said the president would the more regret his inability to be present, as these were the first meetings which the Institution had held under peace conditions—more or less—for the past four years. Assuredly these meetings would mark the beginning of a new era in the history of the Institution, as would also the return of peace in the history of the British Empire. The Institution showed no signs of decreased vitality; not only had its membership been maintained during the war, but now showed remarkable expansion, no doubt a result of the welcome return of peace activities. The "blockade of silence" which was necessarily imposed on all speeches touching on naval affairs had now been raised, and the Institution might look forward to an infusion of fresh vitality into its discussions, on a wider range of technical subjects than had hitherto been considered at its meetings. No one knew better than the members how much had been done during the past eventful years in all branches of naval construction. It was only now, however, that it was possible to lift the veil and make plain to the world much of the great work that was carried on behind the effective screen of secrecy. The two opening papers to be read and discussed were descriptive of some of that work. Many who had given the best proofs of their consummate skill deserved well of their country for keeping ship construction ever to the forefront. Indeed, naval constructors and shipbuilders might well be proud of having provided our splendid sailors with ships that not only enabled them to win victories and patrol the trackless waste of waters in the most threatened areas, but efficiently to keep the British ensign flying in all the seas of the world. The strain had often been tremendous, and countless difficulties had to be met and solved to bring those operations to a successful conclusion.

Much of the work done for the war was necessarily of a special character, which would not, the need being removed, require to be maintained. The protection of merchant ships against mines and submarines, which received so much consideration during the war, was, happily, no longer a question of urgency. But some of the lessons derived from the experience of ships that had been damaged and salved would no doubt prove useful in devising means for protecting ships against injury resulting from collision and stranding. The demand for greater security was one that was constantly made, and the members of the Institution must continue to study those questions closely, so as to achieve, if possible, further steps towards securing the safety of passengers and crews at sea under all conditions.

The industrial unrest which had characterised the period following the cessation of hostilities was a condition usually experienced after all the great wars of the past. Perhaps, however, it was more accentuated under present conditions on account of the greater freedom enjoyed by individuals to assert their views and aspirations and the wider circulation of such views through the Press of all countries. A natural feeling was prevalent that after all the hardships and sufferings of the great war, the conditions of life should be improved for all classes of the community. Unfortunately these desires came at a time when it was particularly difficult to restore the normal conditions of life in pre-war days. The cost of living had been largely increased by the inevitable extravagance of war, and, owing to the vast demand, the supplies of the world, diminished by wastage and neglect, were still quite inadequate for all needs. The pent-up feelings of thousands of individuals whose sufferings

or whose grievances had been borne in silence while the great decision was still hanging in the balance, now clamoured for redress, as though the millennium could be brought about at the word of the magician. The many advances in wages which those in power found it necessary to make from time to time to keep labour in a good humour during the course of the war, seemed to have developed among the workers of the primary industries something like a chronic hunger for higher wages and shorter hours. While it would readily be admitted that there had, in the past, been many just claims for such concessions, it was equally certain that no country and no industry could afford to continue indefinitely along the path of increased cost of production. Much had been heard about the rights of individuals, but little about their duties to the State. The right to live, however, was just as much a prerogative of the State as of the individual, and no State could continue flourishing if its trade was driven to stagnation by impossible demands, either of workers or employers.

There were already unmistakable signs that certain great industries in this country were suffering from the unhealthy atmosphere of the present time. It was perhaps a critical time, when industrial temperature was at fever heat. Experts or controllers prescribed a variety of remedies, and in the dilemma created advice was sought first from one and then from another. But nature would have her say; vitality and subsequent recovery were still dependent upon nature's laws. Those laws held sway in industry and commerce just as much as they did in the human body or the inanimate world, and while the laws of man might rightly temper industrial competition, it was certain that to ignore the fundamental conceptions underlying human enterprise was inevitably to court disaster. It was only necessary to look at Russia to see the holocaust of lives and endless human misery which could result from social upheaval by ignorant agitators working upon the still more ignorant minds of their followers. Fortunately for this country the level of intelligence was high, and the common sense of those who made up the bulk of the community was a formidable barrier to those others who would overthrow the social order for their own selfish ends.

The power now wielded by the trade unions of the country was one of the most important factors for good or ill in gauging the future of its industrial development. It rested largely with those organisations to say whether they would use their powers for the common good or merely to obtain better conditions for the members of their individual unions, without regard to the general effect upon the life of the community. The country had fought for the world's freedom against the tyranny of a military despotism, and the speaker would urge that the country should be kept free of industrial despotism, which might be quite as harmful in its effects as the tyranny over which we had successfully triumphed. What Lord Durham had said at the same time last year about the dangers of choking the natural expansion of shipping and shipbuilding by too much Government bureaucracy held good to-day with even more force.

Now the German peril had been met, and with the passing of that peril we should have to look to the period of reconstruction to set our house in order and face the industrial competition which would inevitably return with the conclusion of peace. This would have to be done by concentrating effort not only upon the betterment of individual conditions and by education and by housing reform, but by so organising the industries that while these should enjoy the benefits arising from co-ordination and effort they should be free from the trammels of official control, particularly from the control of those unacquainted with the needs of the industry. The greatness of Britain had for centuries been bound up with her ships and shipping, and her supremacy in shipping and shipbuilding had been the result of long years of effort and of the survival of types which proved their fitness for service by the gradual process of weeding out the least efficient. Stimulus to invention came with the freedom given to men of genius and courage to prove their worth in the open field of world competition. No artificial State aid could, in the long run, be a substitute for industrial energy and enterprise. In the newly formed Ministry of Ways and Communications the shipping industry had been paid the compliment of being left outside the scope of its operations. Shipbuilders asked nothing better than to be left free to work out their own destiny.

There was much leeway to make up. Four and a half years of ruthless war on commerce at sea had left large gaps to be filled. The needs for new ships were clamant. Across the Atlantic shipyards had sprung up like daisies in the night, and a great new industry had been organised, in a country of great organisations, on a scale and at a speed unparalleled in the annals of shipbuilding, or, indeed, any other industry. The plant there was, in most cases, of the best and newest type, the workers being coached by a system, and the knowledge of a lifetime had been imparted, or as much of it as could be absorbed, in the course of a few months. Standardisation in the production of parts had been carried to great lengths to ensure rapid production and economy of material and effort. Notwithstanding all this display of intelligence and co-ordinated effort, and notwithstanding also the reduction in individual output in British yards, due in part to the dispersal and dilution of skilled labour and other causes, Lord Bristol believed he was right in saying that the cost of production still showed a balance in our favour. The magnitude of the American contribution to the world's shipbuilding output could be gauged from the figures published by Lloyd's Register for merchant ships building during 1918. The total output for Allied and neutral countries was nearly 5,500,000 tons, of which no less than 3,000,000 tons were built in America. This total for one year was higher than the whole output of the United States for the ten years ending 1916. The corresponding figure (for 1918) for the United Kingdom, excluding war work, was only 1,348,000 tons, which fell very short of expectation.

The perils from submarine warfare had caused a movement to take shape for the international abolition of submarines. He could wish that the world were really, finally, and honestly of opinion that not only should submarines, but also bomb-dropping aircraft, long-range guns, torpedoes and gas-filled shells be no longer considered in accord with the laws of nations and humanity. Pending, however, the thinking out of some satisfactory guarantee, making it certain that no nation that might contemplate a future surprise war should be able surreptitiously to prepare for the hasty manufacture of such engines of war in peace time, he could only look upon the movement as a more or less Utopian idea, incapable of being universally enforced.

Ships of the British Navy.

The meeting then proceeded to the consideration of the papers which were down for reading. The first two papers were taken together. They were entitled, "Ships of the British Navy on August 4, 1914, and Some Matters of Interest in Connection with their Production," by Sir Philip Watts, K.C.B., and "Naval Construction during the War," by Sir E. H. Tennyson d'Eyncourt, K.C.B. In the absence of Sir Philip Watts, owing to illness, his paper was read by Sir William E. Smith. The second paper was read by its author. We reproduce Sir Eustace d'Eyncourt's paper on page 482 of this issue. Sir Philip Watts's paper we will reprint later. The matter of Sir Philip's paper is sufficiently indicated by its title. It was of necessity largely statistical and tabular, and its details are in no way necessary for a proper understanding of the discussion.

In connection with Sir Eustace d'Eyncourt's paper, a new tabular statement comparing the main armaments of British and German ships before and after the war was circulated. This statement, which we reprint at the top of the next column, shows to what a very great extent we led in adding heavy armament during the years from 1914 to 1918, and that Germany only built two 15-in. gun ships.

Admiral Sir Reginald Custance was the first speaker in the discussion, being called upon by the President. He said he was reluctant to speak. He would have preferred to hear some one who had taken part in the war. The papers were most

Battleships and Battle Cruisers.

(Dreadnoughts and later Ships only.)

Number of Guns of Main Armament on British v. German.

August 4, 1914.		Added during the war, less losses.			
		Up to May 31, 1916.		Up to November 11, 1918.	
British.	German.	British.	German.	British.	German.
15 in. —	—	64	8	100	16
14 in. —	—	10	—	10	—
13·5 in. 124	—	28	—	20	—
12 in. } 148	184	14	48	minus 12	56
11 in. }					
Total 272	184	116	56	118	72
Weight of Broadside— 279,100 lb.	116,600	190,340	52,840	226,600	77,500

We also had 12 in., 14 in., and 15 in. guns on monitors, but these are not taken into account in the above table, nor are guns on pre-Dreadnoughts counted.

The above table shows that at the beginning of the war, we had in our capital ships, Dreadnoughts and battle cruisers 272 (German 184) big guns with a total broadside of 279,100 lb. (German 116,600 lb.), and by the end of the war we had added one hundred 15-in. guns, besides 13·5-in. &c., and a net addition of 226,600 lb. broadside against sixteen 15-in. and fifty-six 12-in. with a broadside of 77,500 lb. to the German Navy.

We began with an advantage of 140 per cent. weight of broadside.

At Jutland we had an advantage of 175* per cent. weight of broadside.

At finish we had an advantage of 160 per cent. weight of broadside.

* If two ships of Royal Sovereign type only just commissioned are not counted, above percentage becomes 160.

The above figures only include the British and the German Fleets; no account is taken of any of the Allied Fleets or of the Enemy Allied Fleets.

useful contributions to their subjects, but might, perhaps, be made even more so to laymen like himself. He would ask Sir Eustace d'Eyncourt if he could not in his tables add percentages showing what proportion of the displacement of the ships had gone in armour, what in armament, what in speed, &c. If this were done outsiders like himself might be able to pick out the law or principle on which the line of development had been founded. One of the main things that struck one in connection with Sir Eustace's paper was that, for the first time, the naval constructors had had a blank cheque to build what they liked. As far as he was able to judge they appeared to have made good use of their opportunity. The new questions which had arisen had been dealt with, and the results were to be seen in the present strength of the Fleet in all types of ships. The table showing the relation between British and German heavy guns at the beginning and end of the war was very striking.

At the beginning of the war there was undoubtedly a shortage of the smaller type of craft, but this had always been so in every war. In this case the defect was remedied. He remembered that six months before the war he had said that in the event of a war Germany would turn submarines on to sinking merchant ships. He had also said the United States would not stand by and see this done. He thought his prophesies had proved not inaccurate. He had said in the past that a modern war would resolve itself at sea into a struggle between submarines and surface craft, and that it would not be necessary for the main fleet to keep the sea. He mentioned this as illustrating the advantage of studying the past in determining the future. It was most difficult to draw a true lesson from what went on under one's eyes. Mostly people drew the wrong one. The question of armoured cruisers had been referred to in connection with the battle off the Falkland Islands, but he was not sure that that battle supported the ordinary arguments for armoured cruisers. At first armoured cruisers were intended to protect trade routes, but they failed in this because if attacked they had to concentrate for defence. From the German point of view Von Spee's squadron could not be looked upon as having been a success. It concentrated and was destroyed. The Germans could have done enormously greater damage and given us much greater trouble with half-a-dozen Emdens. Again, in the North Sea, where the German High Seas Fleet was partly composed of battle-cruisers, the possession of these ships and their high speed tempted the Germans to send them across and bombard Scarborough. This was no use at all and had absolutely

no effect on the war, and yet Germany risked part of her High Seas Fleet to do it. These battle-cruisers had really been a disadvantage to Germany; they had led her astray.

The convoy system was another illustration which showed that high-speed, lightly protected ships were a mistake. The object in war was to destroy the armed forces of the enemy. If our merchant ships were attacked we placed armed ships alongside them. If the enemy attacked these with superior forces, we strengthened the convoy. We concentrated, and the enemy had also to concentrate. The convoy system again worked round to naval fighting being done by concentrated fleets.

Sir John Biles, the next speaker, said these two papers summarised the work of a lifetime of some of the greatest naval architects in the country, certainly the greatest in the Institution. They formed a most interesting survey and review for consideration at a time which all naval designers had, in a sense, been looking forward to—that was, a time after a great naval war had tested their designs and theories. Sir Eustace d'Eyncourt's paper was most interesting and well illustrated the amount of work which he and the Corps of Naval Constructors had done.

He (Sir John) was particularly reminded of a paper read at the last meeting of the Institution before the war. It was in June, 1914. The paper was concerned with the protection of warships against submarine attack, and it was urged that the Admiralty should make experiments in connection with the protection of the bottom of ships with armour plate. In place of this matters had now developed to the bulge, which was due to Sir Eustace d'Eyncourt, and in his (the speaker's) opinion, was much more effective. He was also reminded by the papers of an interview which he had once had with an amateur naval architect who was head of the Admiralty. This gentleman gave him a lecture on battleship design, and when he (the speaker) suggested a type with six big guns he was told it would be no good and that one must have at least eight big guns. It was interesting to note that we had now got to the six big gun ship. This well illustrated the development of opinion.

There was also a point in connection with the Dreadnought he might mention. Sir Philip Watts had referred to a proposal of Admiral Fisher's in the 'eighties for a ship with twelve big guns arranged in successive tiers three high on the mid line of the ship. This had been turned down because the gunnery people at that time held that big guns one above the other could not be worked. As a result the tiers were flattened out and one got the turrets abreast at the ends of the ship instead of one above another. This was really the way the Dreadnought design developed. Later, of course, gunnery ideas were modified and we got guns one level above another. There was another thing he might mention. In 1895 he put forward an all big gun design for the Japanese Navy. It was not adopted because there was nothing like it in Europe at the time, but the matter was interesting in view of the claim which had been put forward that the all big gun ship was of Italian origin. In conclusion, he would like to refer to the remarkable developments in destroyer design which the Admiralty had made by the application of the turbine and of oil firing for the boilers.

Commander Constructor L. B. McBride, of the United States Navy Department, was the next speaker. He said the two papers under discussion would be read with interest all over the world. They were a lifting of the veil which had hidden so much of the work done in connection with the British Navy during the past five years. The first question that might occur to anyone to ask in connection with the information now made available by the publication of these papers was as to whether a definite type of warship had finally emerged as the best, and whether all the old controversies and discussion would now be a thing of the past. He feared that anyone who had hopes of this sort would be disappointed. In the United States the discussions were certainly going on as merrily as ever. He appreciated Sir Eustace d'Eyncourt's reference to help furnished by the Allies of Britain. They had been very gratified in America to be able to give any assistance to the Royal Navy in its great task. He would like to add that as soon as they came into the war the whole of the knowledge and experience of the Admiralty was at once placed at their disposal. It was only because of this that they had been able to do what they had done. He regretted that Admiral Sims was not able to be there to express for himself his appreciation of all the assistance he had received.

Commander S. V. Goodall said the papers brought to one's mind some criticism of our battle cruisers which appeared in Lord Jellicoe's book. He had rather expected to hear something of this criticism at the meeting. It was, perhaps, not his place to speak in defence of the naval architects, but as anything said in Lord Jellicoe's book was likely to carry effect for some time, and also as Admiral Custance had just told us that the wrong lesson was being drawn from the experience with battle cruisers in the war, he would like to mention one or two points in connection with the matter. In the first place, in discussing this subject it seemed to be assumed that 11 in. of British armour was equivalent to 11 in. of German armour. He thought this assumption and basis was not fair to British armour. Then in connection with the question of heavier armour on German ships, he thought this was probably due to the heavier guns of the British ships. The German authorities had attempted to meet British increase in armament not by increasing their armament so much as by increasing their armour. Then on the question of ranges and angle of descent, there was no doubt both of these had increased since the time when our earlier battle cruisers were designed. In practice, however, matters did not always work out as in theory. On paper the German light cruisers were heavier than ours, but one of the features of the war was the ease with which British light cruisers dealt with German light cruisers.

The fashion at present was to ask for more protection and in the United States more deck and side armour were being fitted to capital ships. The price in speed or armament would, however, have to be paid for this. When Lord Jellicoe spoke of losses of ships as due to lack of sufficient protection it was not quite definite what was meant. If by protection it was intended that ships should be so constructed that it was impossible for a portion of a shell to enter a gun position, then it should be said it was impossible to attain this. There must always be some weak point in the harness. If those who believed in additional protection would examine the facts of the war he thought they would find that where additional protection was necessary it was due first to the increase of range and angle of descent, and second to the increased efficiency of the modern heavy shell.

Admiral the Hon. Sir E. R. Fremantle spoke next. He said what he chiefly wished to do was to thank the authors for their valuable papers. We had spent four years without any official information on the subjects dealt with, and it was of great interest now to learn so much. He would like to ask a question about the bulge. He had seen examples of it himself some time ago and it appeared as if it would largely decrease the speed of a ship. Was this so? He was not implying, of course, that this would be a reason why the bulge should not be fitted. In connection with the matter of armour and protection he had been on board the Lion very shortly after the battle of Jutland, and a high officer had said to him, "these ships cannot be sunk by gunfire." By this had been meant that in no case had the armour been pierced by gun fire. It was not to say, of course, that there might not be a case for re-arranging the armour.

Sir Eustace d'Eyncourt, replying to the discussion, said he could not hope effectively to deal with the large subjects which had been raised, in the little time available. Admiral Custance had asked for the percentage displacement of the new ships representing armour, armament, &c. There was no reason why this information should not be given, and he would endeavour to supply it. As had been said, the Corps of Naval Constructors had had pretty well a free hand for the first time. In developing new types they had to take the principal features and balance the value of one against another. It had been determined that the big gun and high speed should be developed with somewhat reduced protection. On this matter there seemed to be some confusion on the question of battle cruisers. A battle-cruiser had the armament of a battleship, but not her armour. Instead of this she had great speed to give her an opportunity to get her blow in first. If she was armoured like a battleship, she could simply be a battleship. By going to enormous size, however, one could get heavy armour and armament with great speed.

In connection with the matter of six-gun ships mentioned by Sir John Biles, he would say that in getting out their designs they had to consider what gun mountings were likely to be quickly available. They had to cut their coat according to their cloth. In connection with under-water protection against torpedoes, he would say that trials had shown the bulge to be superior to armour on the bottom. Commander Constructor McBride had said they had not yet formed definite conclusions in America. The whole question was still one for discussion. He was glad to hear this. We were still far from the end of development. Admiral Fremantle had asked about the effect of the bulge on speed. If a ship was designed from the first with a bulge there was no bad effect as to speed except, of course, in the sense that one increased the displacement. If one took an existing ship and added a bulge speed was likely to be affected. In the matter of armour, he could say that at Jutland out of all the ships that survived in only one case did a part of a shell get into a vital part of a ship. The ships that were sunk one could only speculate about, but he thought they were destroyed owing to a cordite flash getting into the magazine when a turret was hit.

This concluded the discussion on the two papers, and an adjournment was then made until the afternoon.

THE U.S. NAVAL CONSTRUCTION CORPS.

After the adjournment, Mr. S. V. Goodall, R.C.N.C., M.B.E., read his paper on "The Naval Construction Corps of the United States Navy," which paper we reprint in full on page 464.

The discussion was opened by Sir E. H. Tennyson d'Eyncourt, who said that the paper was of special interest as the author had been in the United States for fifteen months in close touch with the work of the Bureau. The great difference between the Naval Construction Corps of the United States Navy and our own Royal Corps of Naval Constructions was, he said, that the latter was more civilian in character and the former more naval. There were advantages and disadvantages in both systems. In our system training was commenced in the dockyards, and was of a very practical nature, whereas in the American system the training was of a more theoretical character. On the other hand the American system of training involved more experience at sea. The *pros* and *cons* of each system had therefore to be carefully considered in order to determine which was the better. Our Navy and Corps were older than those of the United States, and should have profited by accumulated experience. The speaker had, however, been able to study the question of design and construction in the United States Fleet during the war, and had found that American designers showed great merit. In the matter of accommodation and comfort of the crew, American ships were particularly good. It was extremely difficult to judge which was the better system of training, but in any case he thought members would be very grateful to Mr. Goodall and Admiral Taylor for putting them into the position to make a comparison. He regretted that Admiral Taylor was not able to be present, as part of his early training had been received at the Royal Naval College, Greenwich, and the admiral would therefore have been able to compare the systems most effectively. The speaker thought it probable that our system suited our own requirements best, and that no drastic alterations need be made at once. Some modifications might, however, be made, and the matter would receive careful consideration at the Admiralty.

Constructor-Commander L. B. McBride, of the

United States Navy, who followed, said he was especially glad to see Mr. Goodall's paper on the programme, as it showed the degree of co-operation between the two services that had taken place during the war. Sir Eustace d'Eyncourt had pointed out the difficulty of comparing the Royal Corps of Naval Constructors with the Construction Corps of the United States Navy. Both bodies existed for the same object, viz., to provide their respective navies with a body of expert opinion and knowledge, and to produce material that could be developed by naval officers on the naval and military side. In both cases the Corps of Constructors must act as intermediaries between naval officers and scientific and technical engineers in civil life.

The question of contact of naval constructors with workmen mentioned in the paper was, the speaker thought, bound to arise. Candidates were nominated by Congressmen or Senators, but the selection was made by competitive examinations, the requirements of which were such as could be met by any intelligent boy of 14 with a free school education. The method of choice was thus very wide, boys being eligible up to the age of 20, and they could thus serve an apprenticeship before entering the Naval Academy. This, in fact, was frequently the case. Fully half the boys entering the Naval Academy came from working-class families and they started their careers with a knowledge of life from the workman's point of view.

With regard to the course at the Naval Academy, some criticism had been made of the length of time devoted by the executive officers to naval construction, and of naval constructors to executive matters. This, he thought, was a good feature, as both classes of officers thus spoke in the same language and were thus each better able to understand the problems with which the other had to deal. The speaker thought it would be accepted that a man begins his most useful education when he commences actual work, his earlier training being more in the nature of a basis or groundwork. Both courses aimed at providing an education along broad and liberal lines in which English writing and speaking were regarded as of great importance. If a man having knowledge was unable to impart it to others it was a loss to the nation, and this feature had been much neglected in the United States.

Sir John Biles, who was the next speaker, said that a number of America's best men had been trained in Glasgow University. One thing, he said, was apt to be forgotten in connection with the training of naval architects, and that was that naval architecture was an art as well as a science. It was essential, he thought, that those who taught this subject should also practise it. The most important part of a man's training was that he should be taught to think. A mass of knowledge crammed in was, he said, of little use, and he agreed with the previous speaker when he said that a man's real training commenced after he left college and commenced to practice naval architecture. A proper training of the mind, with some knowledge, was what was required to make the best use of the talent available.

The last speaker was Mr. L. Woollard, who said that it was a matter of considerable interest to those associated at Greenwich with the instruction of the young, to contrast the methods of educating British and American naval constructors. In this country a youth decides at the age of 14 to be a shipbuilder, and finishes his studies at 22 or 23. In the United States a young man commences to specialise at the age of 23, and finishes his special training at 26 or 27. The speaker thought the age of 14 rather young to commence study, but there were advantages and disadvantages in beginning young. At this early age the mind was very receptive, and the student was able to ask any questions without loss of dignity. He did not waste time in learning unimportant matter relating to other trades. At the same time, the general education of naval architects must not be put into the background, and the tendency now was to pay more attention to this matter. At Greenwich the general education given was some part of the mathematical training and some foreign language—usually French. In the United States he noticed that the course for naval constructors included such subjects as memoirs, thesis, public speaking and the principles of accounting, which was very interesting and he regarded the inclusion of such subjects in our course with an open mind. He fully agreed with Mr. Goodall as to the value of training in mathematics.

In his reply, which from lack of time had to be somewhat brief, Mr. Goodall said that he had hoped that the discussion would bring out the merits and demerits of the two systems of training. He was particularly pleased with Commander McBride's contribution, which had explained certain matters more fully than the paper. With regard to Sir John Biles' remarks he agreed that it was necessary to train naval constructors to think, but it was also necessary to train them to act, and the United States' system did this effectively. He also agreed with Mr. Woollard as to the importance of a broad general education. American naval constructors had the advantage of going to sea for two years, and thus had an opportunity of visiting foreign countries. In this way their outlook was broadened. He was glad to hear Sir Eustace d'Eyncourt say that due consideration would be paid to the matter by the Admiralty, with a view to applying certain parts to the British system. The Royal Corps, he said, in conclusion, invited criticism, and was not afraid of the judgment of history on its work. There was, however, no reason why they should not copy some of the methods of the United States, and then perhaps in the next naval war, if such a thing occurred, they might reach an efficiency of 100 per cent. instead of, say, 85 per cent.

The meeting then closed with a vote of thanks to Mr. Goodall.

The Annual Dinner.

The annual dinner of the Institution, held at the Connaught Rooms, Kingsway, on Wednesday evening, was very largely attended, the Marquis of Bristol, Past President, occupying the chair. After the loyal toasts, he proposed "The Naval and Military Forces of the Empire," to which Admiral Sturdee replied. Mr. W. L. Hichens proposed "His Majesty's Dominions Overseas," and the Rt. Hon. Sir George Perley, High Commissioner for the Dominion of Canada, replied. Admiral Tyrwhitt proposed "The Mercantile Marine," Sir Thomas Devitt, Bart., Chairman of Lloyd's Register, responding. Sir J. J. Thomson proposed "The Chairman."

The meetings were resumed on Thursday, and will continue to-day. The programme for these two days is given on page 439 *ante*, and we will continue our report of the proceedings in our next issue.

(To be continued.)

Optical Glass Manufacture in Gas Furnaces.—Investigating the manufacture of optical glass (Journal American Chemical Society, 1918, pages 637 to 639), E. W. Washburn noticed that a certain mixture gave a colourless glass in an electric furnace, but a green glass in a gas-fired furnace. Traces of iron were found in the furnace atmosphere, and the colour appeared chiefly after stirring the melt. The iron gas burners were then replaced by clay-burners; and the walls of the furnace were lined with kaolin; the glass improved in colour, but the kaolin gradually turned red, apparently by absorption of iron from the atmosphere or from the bricks behind. A possible volatilisation of iron should therefore be avoided by water cooling, and bricks free of iron should alone be used in furnaces for optical glass when the green colour must be suppressed.

American Coal for Scandinavia.—The supplies of coal having gradually diminished, the Danish authorities have been surveying the position with somewhat discouraging results. The stocks for March 1 were smaller than for January 1, although the consumption was on the increase. The monthly consumption has risen from 170,000 tons to 200,000 tons, and the stocks in hand on March 1 amounted only to 609,000 tons. The average amount imported per month during 1919 has been 166,000 tons or 20,000 tons less than the monthly average for 1918. The imports from Germany have stopped, all the coal now imported into Denmark coming from Great Britain. As there is some uncertainty about the quantities obtainable from England under the present circumstances, the Danish State Railways have placed some orders for coal in America, but although fairly substantial, they must at present be looked upon only as trial orders. The first American coal is expected to arrive about the end of April, and this has been bought c.i.f. Sweden is also beginning to consider the importation of American coal.

IRON AND STEEL STOCKS.

The Minister of Munitions desires to draw the attention of all concerned to the Order made by him on January 7, 1919, known as the Steel and Iron (Purchase and Returns) Order, 1919. It may be explained that during the war, part of the cost of production of iron and steel was met by direct subsidy from the Government. The subsidies in connection with the manufacture of pig-iron have been continued to April 30, 1919, and in consequence the prices of pig-iron (as well as of manufactured iron and steel made therefrom) have been restricted to prices below the economic level. After the withdrawal of subsidies at April 30, the entire cost of manufacture will have to be met by the iron and steel makers.

It was explained in the Ministry notice, published on December 2, 1918, that steps would be taken to prevent any hoarding of subsidised material during the period for which the subsidies were continued. For this purpose the above-mentioned Order was passed. It provides in effect that no person is entitled to increase his stock of iron and/or steel by more than 100 tons, except under a permit from the Ministry, and that such permits should only be granted on condition that the holders should repay to the Ministry a drawback (representing the subsidies paid on the material by the Ministry) in respect of all such stock which may be held by them on April 30, 1919, exceeding by more than 100 tons the amount of stock held by them on October 31, 1915, or October 31, 1918, whichever is the greater. The drawback referred to, which has been fixed at 30*s.* per ton in respect of iron and/or steel, is a refund to the Government of the subsidies paid by it in respect of material which has not at that date been incorporated in any structure or plant or work in progress.

The Order further requires all persons who, on April 30, 1919, hold a stock of iron and steel, or either of them, of 100 tons or more to furnish to the Controller of Iron and Steel Production within fourteen days after April 30, 1919, a true and complete return of the stock of iron and steel held by them (*a*) on October 31, 1915 or October 31, 1918, whichever shall be the greater; and (*b*) on April 30, 1919. Forms of return for the purpose of the Order may be obtained on application to the Controller, Iron and Steel Department, Ministry of Munitions, Whitehall Place, S.W. 1.

The Minister of Munitions desires to point out that the Order applies to all persons whether iron and steel makers, merchants, stockholders, engineers, shipbuilders or other users of iron and steel, who hold over 100 tons of iron and/or steel on April 30, next. Instructions as to the classes of iron and steel to be included will be found on the return form referred to. It should be added that this return is called for under the powers conferred on the Minister of Munitions by the Defence of the Realm Act and Regulations, and any person failing to comply with the Order is liable to the penalties provided under the Act.

Non-Ferrous Materials.—The following particulars are published of the stocks (exclusive of old metal and scrap) in this country in possession of the Minister of Munitions on April 1, 1919: Copper, 48,702 tons; spelter, G.O.B., 27,676 tons; spelter, refined, 10,371 tons; aluminium, 11,210 tons; soft pig lead, 96,456 tons; nickel, 2,389 tons; antimony regulus 4,361 tons.

British Association Fuel Economy Committee.—The above committee, which was originally appointed in 1915 and issued its first report in 1916, has, owing to the urgency and importance of the coal situation and fuel economy in connection with reconstruction problems, been reappointed to continue its investigations upon the various economic, scientific and technical issues connected with the production and utilisation of coal and other fuels. Professor William A. Bone, F.R.S., has been reappointed chairman, with Mr. H. James Yates, vice-chairman, and Mr. Robert L. Mond as secretary. The General Committee of 33 members includes representatives of the Association of British Chemical Manufacturers, Coke-Oven Managers' Association, Federation of British Industries, Institution of Electrical Engineers, Institution of Gas Engineers, Institution of Mechanical Engineers, Institution of Mining and Metallurgy, Institution of Mining Engineers, Iron and Steel Institute, Society of British Gas Industries, and Society of Chemical Industry. It is divided into three sub-committees: (A) Chemical, General and Statistical, presided over by Professor Henry Louis, with Professor W. W. Watts as vice-chairman; (B) Carbonisation and Metallurgical presided over by Sir Robert Hadfield, Bart., F.R.S., with Mr. Alfred Hutchinson as vice-chairman; and (C) Power, presided over by Mr. C. H. Wordingham, with Mr. W. H. Patchell as vice-chairman. The Executive Committee, which consists of Sir Robert Hadfield, Sir Joseph Walton, M.P., Professors W. A. Bone, Henry Louis and W. W. Watts, Dr. H. S. Hele-Shaw, Messrs. A. Hutchinson, R. Mond, W. H. Patchell, H. Woodall, C. H. Wordingham and H. James Yates, meets in London on the second Wednesday in each month. The committee is now compiling data and information concerning a number of subjects of public interest, including (*inter alia*) such questions as: (1) The economic aspects of coal production in Great Britain, (2) low temperature distillation of coal, (3) future standards for public gas supplies, and (4) the proposed electric power scheme, &c., and invites individuals, firms or institutions who may possess information of value to place it at the disposal of the committee. All communications should be addressed to Professor W. A. Bone, F.R.S., at the Imperial College of Science and Technology, South Kensington.

NAVAL CONSTRUCTION DURING THE WAR.

By Sir EUSTACE TENNYSON D'EYNCOURT, K.C.B., Vice-President.

HAVING obtained the sanction of the Admiralty to give some particulars of vessels added to the fleet during the war, I suggested to the Council of the Institution when putting forward proposals for reading a paper, that in view of the very large amount of design work and construction carried out by the Admiralty during the period under review, it would, on the whole, be most useful and interesting to give a sketch and general summary of all the work rather than select a few types of warships and give a more detailed account of their design and construction.

I need hardly say that within the limits of time and space available for a paper read at this meeting it would be impossible to go fully into more than one or two of the most important designs, although perhaps it may be thought that a complete story of some of them, such as the Renown and Repulse, or the monitors, might make more attractive reading to our members. Still as the accounts of so many other important types would have had to stand over it appeared that the best course would be, as I have said, to give a general account of as many as possible of the ships added to the fleet during the last four and a half years, and this I will endeavour to do.

Immediately after war was declared, great pressure was exercised to complete the ships then building for the Navy, and to order such other vessels as could be designed and finished in the shortest possible time. Many very wise people told us the war would only last a year or possibly eighteen months—in fact that it could not be carried on for a longer period.

This view necessarily coloured all that was done in the way of naval design and construction. Generally speaking, therefore, the construction of new battleships was ruled out. With the acquisition of the Agincourt, Erin and Canada, which were building here for foreign Governments in private yards, and bearing in mind the early completion of the remaining two vessels of the "Iron Duke" class, shortly to be followed by the vessels of the "Queen Elizabeth" class, we had a great preponderance of heavier capital ships, or Dreadnoughts, over the enemy, and as this class of ship takes longer to design and construct than any other, it was obviously a prudent course to concentrate on such types as were specially needed and could be built more quickly.

It should also be remembered that the menace of the submarine, which was from the first beginning to loom as a vital factor in the war, pointed in the direction of large numbers of patrol boats, torpedo-boat destroyers, and smaller types of vessels to deal with this menace. No time, therefore, was lost in placing orders for additional destroyers, submarines, light cruisers, sloops, minesweepers, patrol boats, &c.; and it very soon became clear that the dockyards and the regular warship-building contractors would not be able to cope with the mass of new construction that was required.

Accordingly, orders for many of the last-named classes were placed with builders who had hitherto only been accustomed to mercantile work. With the arrangements that were made, however, for superintending and overseeing the work by the Admiralty, with the assistance of the registration societies—Lloyd's and the British Corporation—very little difficulty was experienced in getting the work satisfactorily carried out by the firms new to this class of shipbuilding, and I think the results show what success attended the arrangements made.

To take ships added to the Navy during the war in the proper order, it is necessary to begin with battleships of the "Iron Duke" class. The particulars of all previous Dreadnoughts are pretty well known, and have been published. The "Iron Duke" class, of which there were four, followed the "King George V" class both in sequence of time and in general characteristics. The same main armament, similarly arranged, with the five turrets all on the centre line of the ship, was adhered to, the chief difference in the "Iron Dukes" being that instead of the 4-in. guns forming the secondary armament, a battery of twelve 6-in. guns protected by 6-in. armour was, after considerable discussion, finally decided upon. The protection also was somewhat increased over that of the King George V, involving an increase in dimensions over any of our previous battleship, due to the addition of these weights and of other items. Two of the class had been laid down in January, 1912, and two in May, the four vessels being completed in March, June, October and November, 1914, so that two were ready just before, and two shortly after, the declaration of war. Four torpedo tubes were carried in lieu of three in the previous ships, and after the Battle of Jutland, a considerable amount of additional protection was added over the magazines—a course which was practically adopted in all our ships at that time as a precautionary measure. Only in one case was any portion of a shell found to have penetrated below the protective deck; but with the ever-increasing range at which actions have been fought, and the increasing penetration of improved shell, the danger of the decks being inadequate had to be considered.

The tables on the opposite page give general particulars of these ships and of all the others with which I am dealing in this paper. It should be mentioned, however, that the speed obtained on trial was approximately 22 knots, or about a knot in excess of the legend speed.

Special interest is attached to this class, as the Iron Duke was the fleet flagship during the whole time of Admiral Jellicoe's appointment as Commander-in-Chief, and she was in action at Jutland with her sister ships. The Marlborough, it should be specially noted, was the only British battleship of the post-Dreadnought type struck by a torpedo during the whole war, and the value of the longitudinal protective bulkhead and of the subdivision and arrangements adopted was clearly shown, as the ship was able to remain in the line, no vital damage being done. She was afterwards safely docked in the Tyne and repaired. This is, I think, specially interesting, as many of our older ships, some with centre-line bulkheads and with other arrangements not so good for dealing with under-water damage, were sunk in the Dardanelles and elsewhere by enemy torpedoes.

The next type to note is the "Queen Elizabeth" class of the 1912–13 programme. Three of these vessels, after taking a little more than two years to build, were completed in January, March and October, 1915. The other two were completed in February, 1916. A very considerable departure was made in the Queen Elizabeths from any previous dreadnoughts, the 15-in. gun taking the place of the 13·5-in., and the designed speed being increased by 4 knots over our previous Dreadoughts, whilst the secondary armament was similar to that of the Iron Dukes, consisting of 6-in. guns. Their very great increase of speed involved practically doubling the horse-power necessary to give the 25 knots desired, and the great increase in the weight of the 15-in. guns and mountings over the 13·5-in. meant accepting only four turrets with eight 15-in. guns, as against five turrets with ten 13·5-in. guns in our previous ships, and even so, the armament was considerably heavier. The further great departure from previous practice in battleships was the adoption of oil only as the fuel. This necessitated special arrangements of the oil bunkers, many of which were 30 ft. in height, and required special construction to withstand the head of oil. The armour and protection were fully maintained as compared with previous ships, but all these additions involved increasing the displacement to 27,500 tons.

In the Battle of Jutland, the Fifth Battle Squadron, consisting of four vessels of this class, were heavily engaged for several hours, and although they inflicted and sustained heavy punishment, especially in the case of the Warspite, all the vessels gave a splendid account of themselves and were not seriously damaged or put out of action. After the Battle of Jutland, additional protection was added to the magazines. It may be mentioned that the oil fuel proved a complete success, it being found easier to keep up a high sustained speed, and a smaller complement also is, of course, involved, as there is great saving in *personnel* as against that required for a coal ship.

I should mention that Sir Philip Watts was responsible for the design of the "Iron Duke" and "Queen Elizabeth" classes, thus completing a series of 27 battleships of the Dreadnought class designed and built during his tenure of office at the Admiralty—in addition to the large number of battle cruisers and light cruisers and other vessels built during that period—truly a great record.

BATTLESHIPS OF THE "ROYAL SOVEREIGN" CLASS (PLATE XXXIII).

The next in order came the "Royal Sovereign" class of the 1913–14 programme. These vessels were to have the same armament as the Queen Elizabeth, but as there was some question about the supply of oil fuel when the design was discussed, it was decided to revert to coal, and also to accept the slower speed of 21 knots, which would make them more homogeneous with other Dreadnoughts. Subsequently, when the vessels were in process of construction and the great advantages of the use of oil fuel with other types of warships became apparent, it was decided to change from coal to oil, and it was anticipated that increased power giving a speed of about 23 knots would be obtained. As a matter of fact when fully laden with about 4,000 tons of oil, the Revenge attained 22 knots, which was equal to about 23 knots in the designed load condition. A different disposition of deck and side armour was also adopted by which the thick protective deck at the centre of the ship was brought up to the level of the main deck; this portion of the protective deck being thus well above the level of the deep load-line, and giving more protected freeboard in the damaged condition than in any of our earlier battleships. This was an important feature, a somewhat reduced metacentric height was decided upon for these ships with a view to making them steadier gun-platforms than some of the ships with larger G.M. The vessel was provided with good under-water protection, which in certain of the ships was further reinforced by adding outside bulge protection. This was done to the Ramillies before her launch and also to two other vessels of the class after they had been in commission some time, during refit, and it is proposed to add the bulge to the remaining two ships of the class when opportunity offers. The addition of bulges was suggested by myself originally for the "Edgar" class for which I designed this form of protection in 1914, after considerable experiments had been made. The results have proved the efficiency of the bulges. Further particulars of the "Royal Sovereign" class can be seen from Plate XXXIII and the table.

BATTLESHIPS TAKEN OVER FROM FOREIGN GOVERNMENTS.

The three ships taken over from foreign Governments were of different types, as shown in the table of particulars and Plates XXXIII and XXXIV.

H.M.S. Agincourt (Plate XXXIII) was commenced in September, 1911, for the Brazilian Government, when I took out various designs (got out under Mr. Perrett, at Elswick) to Rio de Janeiro, and finally settled on the design of the Agincourt, after modifying it very considerably on the spot. The Brazilian authorities, after much discussion, decided upon fourteen 12-in. guns, twin-mounted in seven turrets. This involved a ship with a length of 632 ft. between perpendiculars and 671 ft. 6 in. over all. The main armour was somewhat lighter than our British Dreadnoughts (as seen from the particulars opposite), and in other respects, such as fuelling facilities, the ship hardly came up to the British standard. However, she was well reported on and the 14 big guns were liked by the gunnery officers, who preferred a large number of guns for their salvoes. Certain alterations had to be made to fit her for our service, but in the main she was left as designed. I should perhaps mention that in 1914 she was transferred from the Brazilian Government to the Turkish Government, and when war broke out she was on the point of leaving for Constantinople, when she was taken over.

The design of the Erin (Plate XXXIV) was settled by the three firms — Armstrongs, Vickers, and Brown— in consultation with the Turkish authorities, for whom the vessel was built, being commenced in November, 1911. In general characteristics she more nearly followed the "King George V" class than any other British ship, except that the secondary armament consisted of 6-in. guns, as in the "Iron Duke" class. This vessel also was taken over by the British Government in August, 1914, and certain modifications made to fit her for the British service. In respect of quantity of fuel carried, the Erin was below the standard adopted for vessels designed for the British Navy.

The third ship taken over from a foreign Government was ordered and commenced in 1911 at Elswick, from designs prepared by Mr. Perrett for the Chilean Government. There were two ships of the class, the Almirante Latorre (now the Canada), and the sister ship the Almirante Cochrane (now the Eagle). The Canada (Plate XXXIV) has ten 14-in. guns, twin-mounted, in the centre line, and was originally designed to have twenty-two 4·7-in. as the secondary battery, but this was subsequently altered to sixteen 6-in. guns. The protection, again, was somewhat lighter than that of our Dreadnoughts, but the speed was rather higher, viz., 22½ knots, and as a matter of fact this speed was considerably exceeded on trial. The ship was taken over by British Admiralty in September, 1914, and completed, after certain necessary modifications, a year later. Her fuel consisted of coal, with the addition of a certain amount of oil, as in most of our battleships. The sister ship, Almirante Cochrane, remained in an uncompleted condition on the stocks at Elswick till the spring of 1917, when she was taken over by the British Government and rearranged as an aircraft-carrying ship. She was renamed H.M.S. Eagle, and as a compliment to the United States Navy, she was, at the request of the Admiralty, launched by Mrs. Page, the wife of the late American Ambassador. The above record finishes the list of battleships proper which are completed for service during the war.

LARGE BATTLE-CRUISERS.

Coming to the battle-cruisers, particulars have already been published of all these down to H.M.S. Tiger. This ship was included in the 1911–12 programme and followed on the Queen Mary, the general features of the two ships being much alike, the chief differences being that the secondary armament of the Tiger is twelve 6-in. guns in lieu of sixteen 4-in. in Queen Mary, and Tiger has two submerged torpedo rooms, whereas the Queen Mary had only one.

After the design was approved by the Board, the ship was ordered and laid down at Clydebank on June 12, 1912, and completed in October, 1914. In common with so many of our ships completed during the war, the early commissioning and joining of the Fleet was so imperative, that no exhaustive trials in deep water were carried out, but the runs made on the Polperro Course showed that the designed power of 108,000 shaft horse-power could be obtained with little difficulty, corresponding to a speed of 30 knots. During the progress of the design, the oil fuel capacity was very largely increased in case of need, the original tanks which only allowed for 1,100 tons were supplemented to admit of a maximum oil stowage of 3,480 tons, in addition to the 3,320 tons of coal; but it is not usual for the vessel to carry this full fuel stowage, at any rate, of oil.

BATTLE-CRUISERS RENOWN AND REPULSE. (Plate XXXV.)

At the commencement of the war two additional battleships of slightly modified Royal Sovereign type, viz., the Renown and Repulse, had been laid down, but in view of the long time it would take to complete these ships, the construction was not pressed forward. Immediately after the battle of the Falkland Islands, in which our battle-cruisers Invincible and Inflexible, in company with other smaller cruisers, annihilated Von Spee's fleet, the value of the battle-cruiser type became very apparent, and on the initiative of Lord Fisher, then First Sea Lord, it was decided to stop the construction of the Renown and Repulse as battleships and to alter the design completely into that of very fast battle-cruisers. I received instructions to re-design these ships about Christmas, 1914. The new design had to give a speed of 32 knots, with the largest number of guns possible for such a vessel, and with protection similar to the Invincible and Indefatigable classes. A modified form of bulge was adopted in these ships to give additional underwater protection against torpedo attack. Proposals are now under way for still further adding to this bulge protection.

The general outline design was completed and approved in ten days, and six 15-in. guns were adopted as the main armament, the secondary armament consisting of seventeen 4-in. guns, of which fifteen were mounted in five specially designed triple gun mountings. Owing to the circumstances, referred to above, it was necessary that the ships should be completed at the earliest possible date, and I suggested that the Tiger's machinery should be repeated with some additional boilers, and with the

* Paper read before the Institution of Naval Architects, April 9, 1919.

TABLE I.—PARTICULARS OF BRITISH WARSHIPS CONSTRUCTED DURING THE WAR.

	Battleships.						Battle Cruisers.		Large Light Cruisers.	
	Iron Duke.	Queen Elizabeth.	Royal Sovereign.	Agincourt.	Erin.	Canada.	Tiger.	Renown.	Courageous.	Furious.
Length between perpendiculars	580 ft. 0 in.	600 ft. 0 in.	580 ft. 0 in.	632 ft. 0 in.	525 ft. 0 in.	625 ft. 0 in.	660 ft. 0 in.	750 ft. 0 in.	735 ft. 0 in.	750 ft. 0 in.
Length overall	622 ft. 9 in.	643 ft. 9 in.	624 ft. 3 in.	671 ft. 6 in.	559 ft. 6 in.	661 ft. 0 in.	704 ft. 0 in.	794 ft. 0 in.	786 ft. 3 in.	786 ft. 6 in.
Breadth, extreme	90 ft. 0 in.	90 ft. 6 in.	88 ft. 6 in.	89 ft. 0 in.	91 ft. 7 in.	92 ft. 0 in.	90 ft. 0 in.	90 ft. 0 in.	81 ft. 0 in.	88 ft. 0 in.
Load draught, mean	28 ft. 0 in.	28 ft. 9 in.	28 ft. 6 in.	27 ft. 0 in.	28 ft. 6 in.	28 ft. 6 in.	28 ft. 6 in.	25 ft. 6 in.	22 ft. 3 in.	21 ft. 6 in.
Displacement in tons	25,000	27,500	25,750	27,500	23,000	28,000	28,500	26,500	18,600	19,100
Shaft horse-power of engines	29,000	75,000	40,000	34,000	36,500	37,000	108,000	112,000	90,000	90,000
Speed at load draught (knots)	21	25	23	22	21	22½	30	32 nearly	32	31½
Fuel at load draught (tons)	900	650	900	1,500	900	1,150	900	1,000	750	750
Coal capacity (tons)	3,250	—	—	3,200	2,120	3,300	3,320	—	—	—
Oil fuel capacity (tons)	1,050	3,400	3,400	620	710	520	3,480	4,250	3,250	3,400
Armament	10 13·5-in. 12 6-in. 4 21-in. T.T.	8 15-in. 12 6-in. 4 21-in. T.T.	8 15-in. 14 6-in. 4 21-in. T.T.	14 12-in. 20 6-in. 2 21-in. T.T.	10 13·5-in. 16 6-in. 4 21-in. T.T.	10 14-in. 14 6-in. 4 21-in. T.T.	8 13·5-in. 12 6-in. 4 21-in. T.T.	6 15-in. 17 4-in. 2 21-in. T.T.	4 15-in. 18 4-in. 14 21-in. T.T.	— 10 5·5-in. 18 21-in. T.T.
Armour—										
Side, amidships	12in., 9in., 8in.	13 in., 6 in.	13 in., 6 in.	9 in., 6 in.	12in., 9in., 8in.	9in., 7in., 4½in.	9in., 6 in., 5 in.	6 in., 1½ in.	3 in.	3 in.
Side, forward and aft	6 in., 4 in.	6 in., 4 in.	6 in., 4 in.	6 in., 4 in.	6 in., 4 in.	6 in., 4 in.	4 in.	4 in., 3 in.	2 in. forward	2 in. forward
Bulkheads, forward and aft	8 in., 6 in., 4 in.	6 in., 4 in.	6 in., 4 in.	6 in., 3 in.	8 in., 5 in., 4 in.	4½ in., 4 in.	4 in., 2 in.	4 in., 3 in.	3 in., 2 in.	3 in., 2 in.
Barbettes	10 in. to 3 in.	10 in., to 4 in.	10 in. to 4 in.	9 in. to 3 in.	10 in. to 3 in.	10 in. to 4 in.	9 in. to 3 in.	7 in. to 4 in.	7 in. to 3 in.	7 in. to 3 in.
Gunhouses	11 in.	11 in.	11 in.	12 in., 8 in.	11 in.	10 in.	9 in.	11 in. to 7 in.	9 in., 7 in.	7 in.
Conning tower	11 in.	11 in.	11 in., 6 in.	12 in.	11 in.	11 in.	10 in.	10 in.	10 in.	10 in.
Protection—										
Vertical plating	1½ in., 1 in.	2 in., 1 in.	1½ in., 1 in.	1½ in., 1 in.	1½ in.	2 in., 1½ in.	2½ in., 1½ in., 1 in.	1½ in.	1½ in., 1 in.	1 in.
Forecastle deck	1 in. amidships	1 in.	1 in.	1½ in. amidships	1½ in. amidships	1 in. amidships	1½ in., 1 in.	1½ in., 1 in.	1 in.	1 in.
Upper deck	2 in. to 1½ in.	2 in. to 1½ in.	1½ in. to 1½ in.	1½ in.	1½ in.	1½ in.	1½ in., 1 in.	½ in.	1 in.	1 in.
Main deck	1½ in. at ends	1½ in. at ends	2 in., 1½ in., 1 in.	1½ in., 1 in. at ends	1½ in.	1½ in. aft	1 in. at ends	3 in. to 1 in.	1½ in., ½ in.	1½ in., ½ in.
Middle deck	2½ in., 1 in.	1 in. amidships	2 in. slope main to middle	1½ in., 1 in.	3 in., 1 in.	1 in.	—	—	—	—
Lower deck	2½ in., 1 in.	3 in., 1 in.	1 in., 2½ in., 3 in. 4 in.	2½ in., 1 in.	—	4 in., 2 in.	3 in., 1 in.	3½ in.	3 in., 1 in.	3 in., 1 in.

	Light Cruisers.				Monitors.						
	Arethusa.	Calliope.	"D" Class.	Raleigh.	Humber.	14-in. Gun Class.	12-in. Gun Class.	Marshal Soult.	Erebus.	9·2-in. Gun Class.	6-in. Gun Class.
Length between perpendiculars	410 ft. 0 in.	420 ft. 0 in.	445 ft. 0 in.	565 ft. 0 in.	261 ft. 6 in.	320 ft. 0 in.	320 ft. 0 in.	340 ft. 0 in.	380 ft. 0 in.	170 ft. 0 in.	170 ft. 0 in.
Length overall	436 ft. 0 in.	446 ft. 0 in.	471 ft. 0 in.	605 ft. 0 in.	266 ft. 9 in.	334 ft. 6 in.	335 ft. 6 in.	355 ft. 8 in.	405 ft. 0 in.	177 ft. 0 in.	177 ft. 0 in.
Breadth, extreme	39 ft. 0 in.	41 ft. 6 in.	46 ft. 0 in.	65 ft. 0 in.	49 ft. 0 in.	90 ft. 0 in.	87 ft. 0 in.	90 ft. 3 in.	88 ft 0 in..	31 ft. 0 in.	31 ft. 0 in.
Load draught, mean	13 ft. 6 in.	13 ft. 6 in.	14 ft. 3 in.	17 ft. 3 in.	4 ft. 9 in.	10 ft. 0 in.	10 ft. 0 in.	10 ft. 3 in.	11 ft. 0 in.	6 ft. 0 in.	4 ft. 0 in.
Displacement in tons	3,500	3,750	4,650	9,750	1,260	6,150	5,900	6,670	8,000	540	355
Shaft horse-power of engines	40,000	40,000	40,000	60,000	1,450	2,000	2,300 to 2,500	1,500	6,000	480 to 800	400
Speed at load draught (knots)	29	29	29	30	12	6 to 7	6 to 7	6 to 7	12	12 to 13	10
Fuel at load draught (tons)	260	300	300	1,000	50	200	200	100	220	—	—
Coal capacity (tons)	—	—	—	800	167	400	350	—	—	—	—
Oil fuel capacity (tons)	810	920	1,050	1,600	90	—	—	235	750	30	45
Armament	2 6-in. 7 4-in. (1 H.A.) 8 21-in. T.T.	2 6-in. 8 4-in. 4 21-in. T.T.	6 6-in. 2 3-in. H.A. 12 21-in. T.T.	7 7·5-in. 12 3-in. (4 H.A.) 6 21-in. T.T.	3 6-in. 2 4·7in. How.	2 14-in. 1 6-in.	2 12-in. 1 to 4 6-in.	2 15-in. 8 4-in.	2 15-in. 8 4-in.	1 0·2-in. 1 3-in.	2 6-in. 1 6-pdr.
Armour—											
Side, amidships	3 in.	3 in.	3 in.	3 in., 2 in.	—	—	—	—	—	—	—
Forward and aft	2 in., 1½ in.	2 in., 1½ in.	2 in., 1½ in., 1½ in.	2½ in., 1½ in.	—	—	—	—	—	—	—
Bulkheads, forward and aft	—	—	1 in. aft	1 in. aft	—	4 in.	6 in.	4 in.	4 in.	—	—
Barbettes	—	—	—	—	—	8 in. to 2 in.	8 in. to 2 in.	8 in.	8 in.	—	—
Gunhouses	—	—	—	—	—	10 in., 7 in., 4 in.	10½ in., 5½ in., 4 in., 2 in.	13 in., 11 in., 4½ in.	13 in., 11 in., 4½ in.	—	—
Conning tower	6 in.	6 in.	—	3 in.	—	6 in.	6 in.	6 in.	6 in.	—	—
Protection—											
Vertical plating	—	—	—	—	—	1½ in.	1 in.	1 in.	1 in.	—	—
Forecastle deck	—	—	—	—	—	1 in.	1 in.	1 in.	1 in.	—	—
Upper deck	1 in. amidships	1 in. amidships	1 in. amidships	1 in. amidships	—	2 in. to 4 in. on slope	2 in. to 6 in. on slope	1½ in., 2 in. to 4 in. on slope	2 in. to 4 in. on slope	—	—
Main deck	—	—	—	—	—	1½ in., 1 in.	1½ in., 1 in.	1½ in., 1 in.	1½ in., 1 in.	—	—
Lower deck	1 in. aft	1 in. aft	1 in. aft	1 in. aft	—	—	—	—	—	—	—

	Submarines.					
	"E" Class.	"G" Class.	"H" Class.	"J" Class.	"K" Class.	"L" Class.
Length between perpendiculars	180 ft. 0 in.	185 ft. 0 in.	164 ft. 6 in.	270 ft. 0 in.	334 ft. 0 in.	222 ft. 0 in.
Length overall	181 ft. 0 in.	187 ft. 0 in.	171 ft. 0 in.	275 ft. 0 in.	338 ft. 0 in.	231 ft. 0 in.
Breadth, extreme	22 ft. 6 in.	22 ft. 6 in.	15 ft. 9 in.	23 ft. 0 in.	26 ft. 6 in.	23 ft. 6 in.
Load draught, mean	12 ft. 6 in.	13 ft. 3 in.	11 ft. 3 in.	14 ft. 0 in.	16 ft. 0 in.	15 ft. 6 in.
Displacement in tons, surface	660	700	440	1,210	1,880	890
Displacement in tons, submerged	800	975	500	1,820	2,650	1,070
Shaft horse-power of engines, surface	1,600	1,600	480	2,500	10,000	2,400
Shaft horse-power of engines, submerged	840	840	320	1,350	1,400	1,600
Speed at load draught (knots) surface	15	14	13	19	24	17½
Speed at load draught (knots) submerged	10	10	10½	9½	9	10½
Oil fuel capacity (tons)	45	44	16	91	200	76
Armament	1 3-in. 5 18-in. T.T.	1 3-in. 4 18-in., 1 21-in. T.T.	— 4 21-in. T.T.	1 3-in. or 4-in. 6 18-in. T.T.	1 4-in., 1 3-in. H.A. 8 18-in. T.T.	1 3-in. or 4-in. 6 18-in. T.T.

	Torpedo-Boat Destroyers.			T.B.D. Flotilla Leaders.		Patrol Boats.	Sloops and Mine-Sweepers.			"China" Gunboats.	
	"M" Class.	"R" and "S" Classes.	"V" and "W" Classes.	"Kempenfelt" Class.	"Scott" Class and "Shakespeare" Class (approximately same)	"P" Class.	Single-screw Sloops, "Flower" Class.	Paddle Mine-sweepers.	Twin-screw Mine-sweepers.	"Fly" Class.	"Insect" Class.
Length between perpendiculars	265 ft. 0 in.	265 ft. 0 in.	300 ft. 0 in.	315 ft. 0 in.	320 ft 0 in..	230 ft. 0 in.	255 ft. 3 in.	235 ft. 0 in.	220 ft. 0 in.	120 ft. 0 in.	230 ft. 0 in.
Length overall	273 ft. 4 in.	276 ft. 0 in.	312 ft. 0 in.	325 ft. 0 in.	332 ft. 6 in.	244 ft. 6 in.	267 ft. 9 in.	245 ft. 9 in.	231 ft. 0 in.	126 ft. 0 in.	237 ft. 6 in.
Breadth, extreme	26 ft. 8 in.	26 ft. 8 in.	29 ft. 6 in.	31 ft. 9 in.	31 ft. 9 in.	23 ft. 9 in.	33 ft. 6 in.	29 ft. 0 in. (58 ft. over paddles)	28 ft. 0 in.	20 ft. 0 in.	36 ft. 0 in.
Load draught, mean	8 ft. 8 in.	9 ft. 0 in.	9 ft. 0 in.	10 ft. 0 in.	10 ft. 6 in.	7 ft. 7 in.	11 ft. 0 in.	6 ft. 9 in.	7 ft. 0 in.	2 ft. 0 in.	4 ft. 0 in.
Displacement in tons	1,025	1,065	1,300	1,650	1,800	573	1,250	810	750	98	645
Shaft horse-power of engines	25,000	27,000	27,000	36,000	40,000 to 44,000	4,000	2,400	1,400	1,800	175	2,000
Speed at load draught (knots)	34	36	34	34	36	22	17	15	16	10	14
Fuel at load draught (tons)	140	150	185	255	250	50	130	—	—	—	—
Coal capacity (tons)	—	—	—	—	—	—	280	150	140	5	35
Oil fuel capacity (tons)	280	300	370	515	500	93	—	—	—	10	54
Armament	3 4-in. 1 2-pdr. 4 21-in. T.T.	3 4-in. 1 2-pdr. 4 21-in. T.T.	4 4-in. or 4·7-in. 1 3-in. 4 or 6 21-in. T.T.	4 4-in. 2 2-pdrs. 4 21-in. T.T.	5 4·7-in. 1 3-in. H.A. 6 21-in. T.T.	1 4-in. 1 2-pdr. 2 14-in. T.T.	2 4-in. or 4·7-in. 2 3-pdrs. —	1 3-in. 1 6-pdr., 2 2-pdrs. —	1 3-in. 1 6-pdr., 2 2-pdrs. —	1 4-in. 1 3-in., 1 6-pdr. —	2 6-in. 2 3-in. —

NAVAL CONSTRUCTION DURING THE WAR.

Fig. 9. LIGHT CRUISERS
ORDERED DECEMBER 1913
"RALEIGH" "EFFINGHAM"
"HAWKINS" "FROBISHER"
"CAVENDISH"

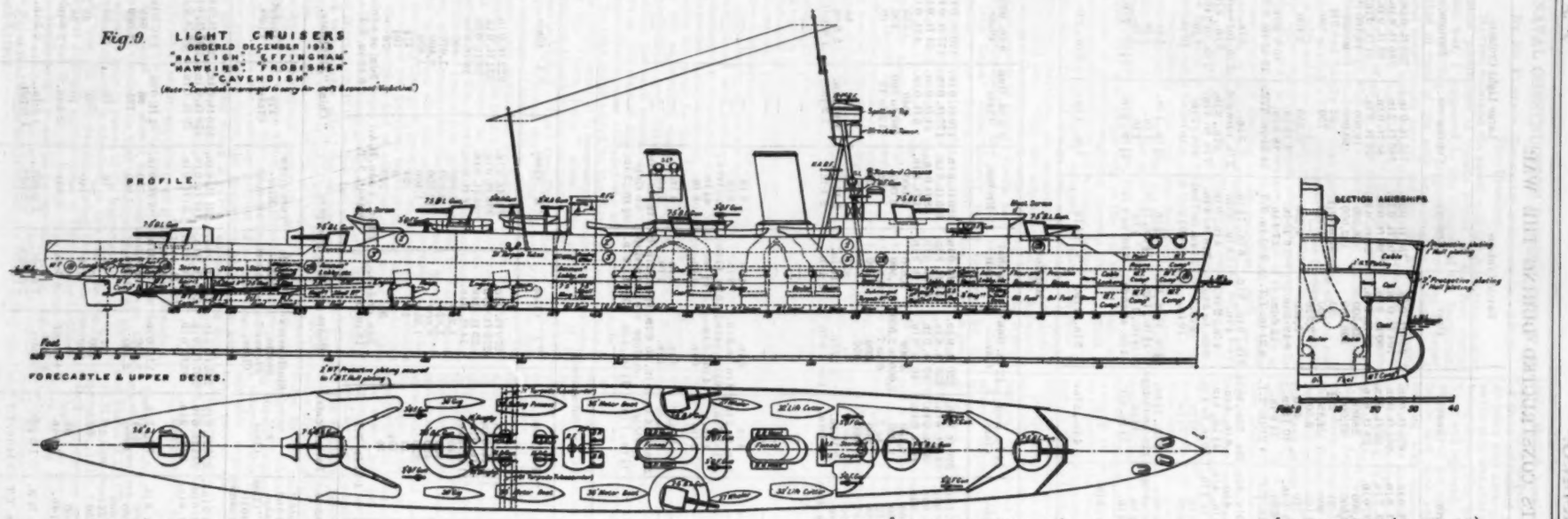


Fig. 10. MONITORS "EREBUS" & "TERROR" (15" GUNS)

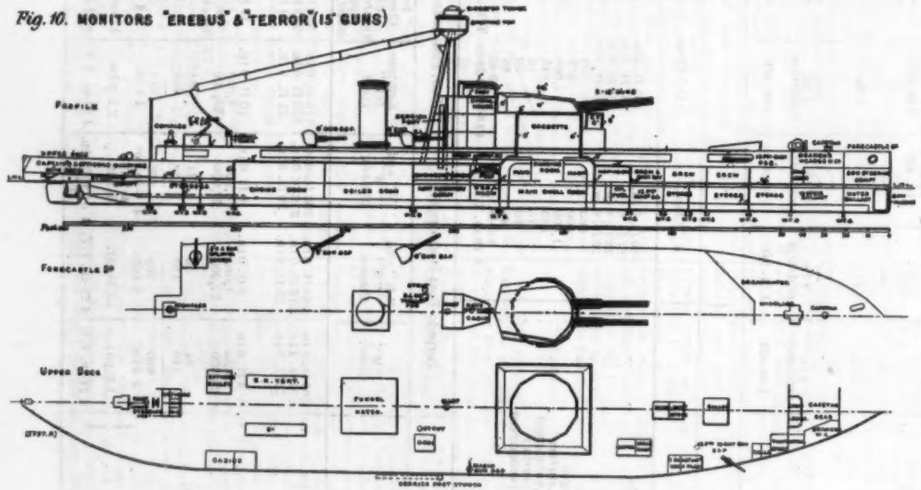
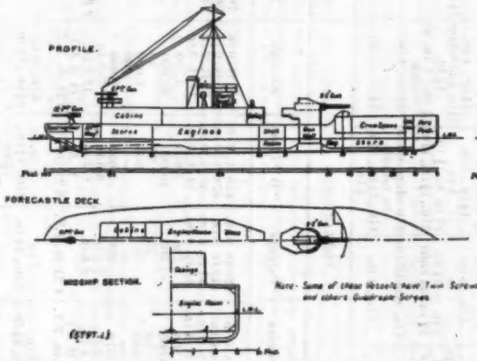
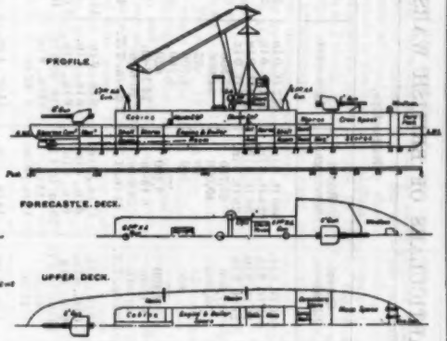


Fig. 11. 9·2" MONITORS. (M 15 to 28.)



6" MONITORS. (M 29 to 33)



extra length it was found possible to obtain the speed of 32 knots, as laid down by the Board. Lord Fisher also insisted that the ships must be completed with fifteen months—an abnormally short time for an entirely new design, without any drawings prepared. This period of completion was not realised, although not greatly exceeded.

By January 21, 1915, the two firms entrusted with the orders, viz., John Brown and Co. and the Fairfield Company, were supplied with sufficient information to enable them to proceed with the structure, and both keels were laid on January 25. All the drawings and specifications were completed by April and the design finally approved in that month. The fuel was to be entirely oil, and with the additional boilers the power expected to be from 110,000 shaft horse-power to 120,000 shaft horse-power—the latter having actually been obtained on trial. The arrangement of the whole ship, showing the protection, is given on Plate XXXV, the plating over the magazines being considerably increased during the construction as a result of the Jutland fight. The Repulse was launched in January, 1916, less than a year from the laying down, and the Renown was launched two months later. The Repulse went through her commissioning trials early in August, and the Renown followed one month later and was completed in September. The speed of Repulse on trial was over 31¼ knots in the deep condition, and the Renown obtained 32·6 knots mean speed on the new measured course off Arran in the normal condition. The ships have been well reported upon at sea and maintain their speed well. I think that the construction of these vessels in a little over one and a-half years from the first order to get out the design, constitutes a record in design and construction of two such important vessels, and reflects great credit, not only upon the Royal Corps of Naval Constructors, but also upon the contractors and all concerned in the construction and completion of the vessels. In fact, the Admiralty conveyed their appreciation of this to me in a letter dated September, 1916.

Large Light Cruisers Courageous, Glorious and Furious. (Plate XXXVI.)

Whilst the designs of the Renown and Repulse were in progress, I received instructions to design some very high-speed ships carrying powerful guns and of a size sufficient to keep their speed in moderate weather, but to have a draught lighter than any existing British or enemy ship of the same class, so as to be able to navigate shallow waters, if required.

As sanction was not likely to be obtained for building more capital ships taking two years or longer to complete, while additional light cruisers had been already approved of, it was decided to build the Courageous and Glorious on the lines of very large light cruisers mounting a few guns of heaviest calibre, so as to be able to annihilate any enemy light cruisers or raiders. They were to have thin protection, similar to our light cruisers, and a speed of not less than 32 knots, the draught being

NAVAL CONSTRUCTION DURING THE WAR.

Fig. 12. "M" CLASS DESTROYER.
ADMIRALTY DESIGN (1914)

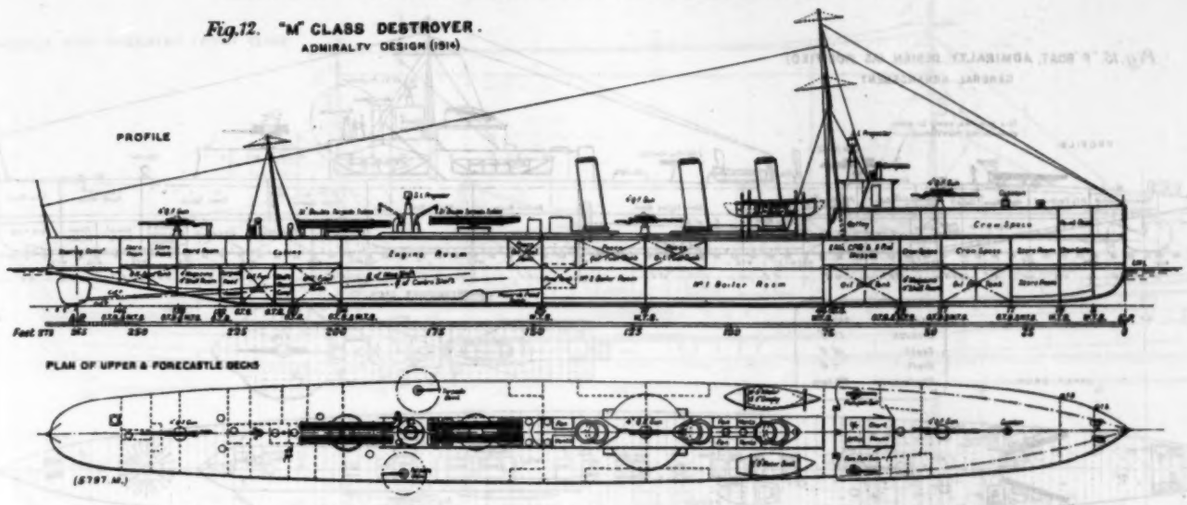


Fig. 13. H.M.S. "VECTIS" ("V" CLASS)
ADMIRALTY DESIGN

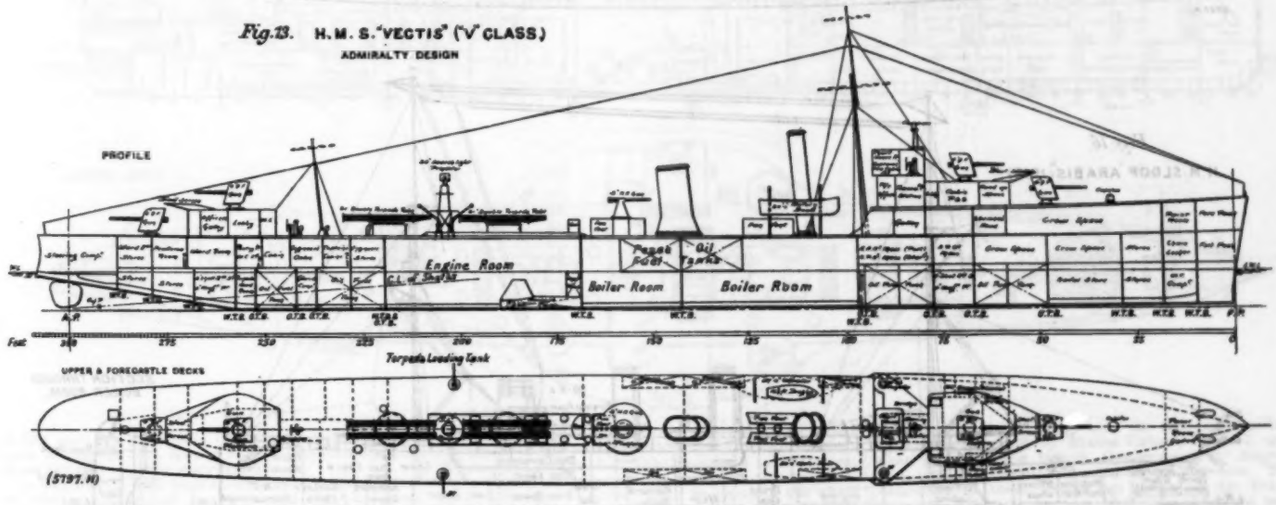
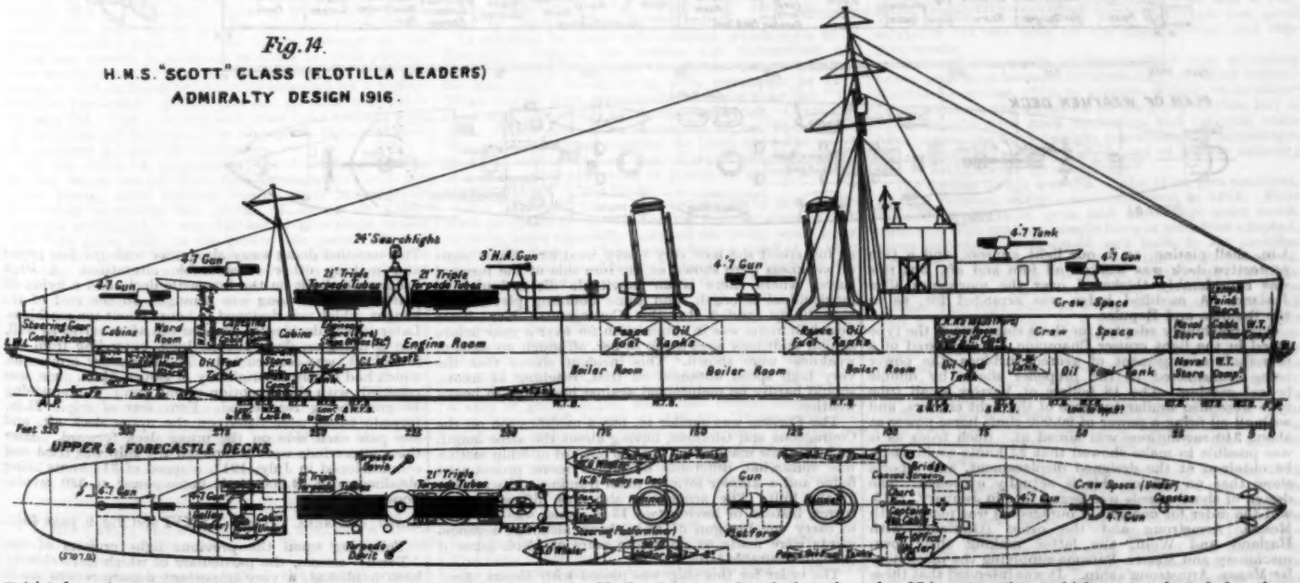


Fig. 14.
H.M.S. "SCOTT" CLASS (FLOTILLA LEADERS)
ADMIRALTY DESIGN 1916.



restricted to about 22 ft., or about 5 ft. less than any existing battleship or battle-cruiser carrying such heavy guns, the main armament of four 15-in. guns in two turrets, one forward and one aft, making them a match for any raider or light cruiser that might be encountered. At this time it should also be remembered that the armaments of ships, especially as regards heavy guns, had to be regulated by the guns and gun mountings which would be available or could be manufactured in the time at our disposal, and this condition applied to the 15-in. mountings which were adopted for these ships. The secondary armament consisted of eighteen 4-in. guns in six triple mountings, similar to the triple mountings of the Renown and Repulse. The side armour consisted of 2-in. protected plating on top of the

NAVAL CONSTRUCTION DURING THE WAR.

Fig. 15. "P" BOAT. ADMIRALTY DESIGN (AS MODIFIED)
GENERAL ARRANGEMENT

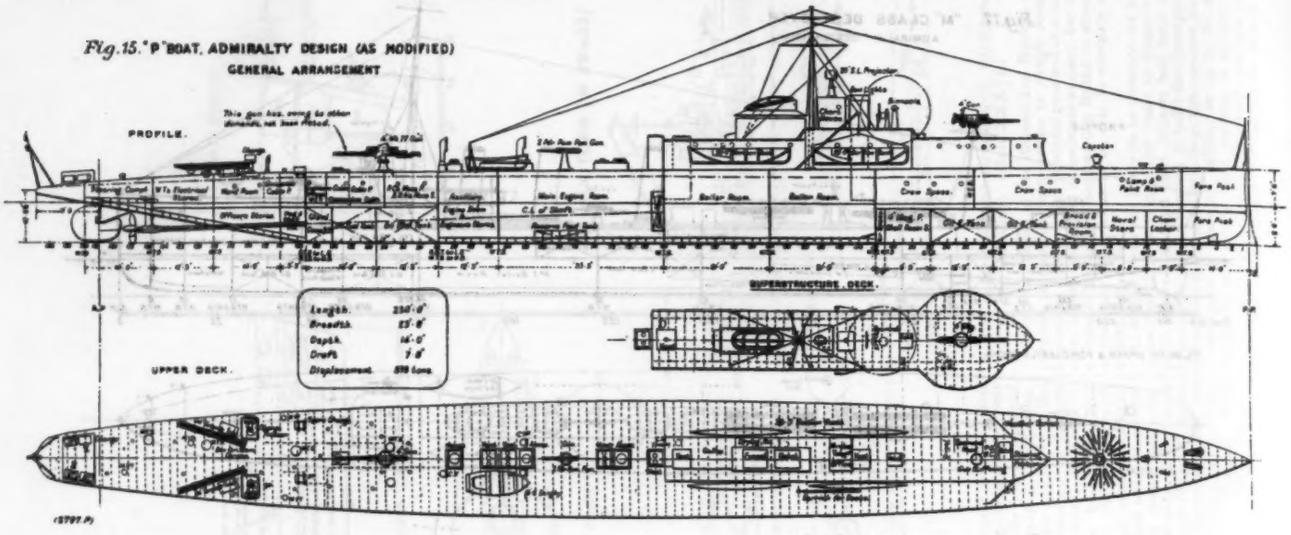
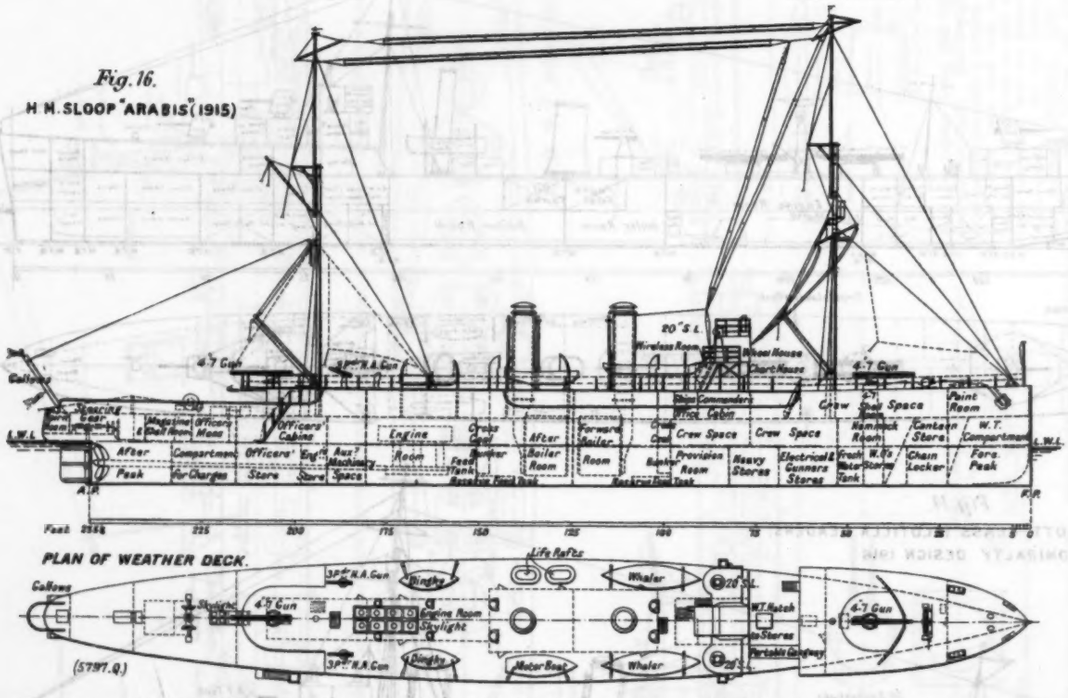


Fig. 16.
H.M. SLOOP "ARABIS" (1915)



1-in. shell plating, as in our light cruisers, and a thin protective deck was worked all fore and aft, but this was considerably thickened over the magazines after Jutland. A modified bulge was arranged for, as in the Renown and Repulse.

The machinery adopted for these ships was of the type fitted in the light cruiser Champion. It consisted of a four-shaft arrangement of geared turbines, the power being transmitted to the propeller shafts by double helical gearing. The 18 boilers of Yarrow small tube type were also similar to those of the light cruisers, and with all-oil firing a power of 90,000 shaft horse-power at about 340 revolutions was aimed at. Such trials as it was possible to make showed that 32 knots could easily be obtained at the designed displacement, and reports show that on service this is actually exceeded. The design of these vessels was begun late in January, 1915, and the order for one ship (Courageous) was placed with Messrs. Armstrong and the other (Glorious) with Harland and Wolff, the latter making their own machinery and Messrs. Parsons supplying the machinery for Messrs. Armstrong's ship. It was intended that these vessels should be built in a year, or as near that as possible, but this was not realised, and the ships were both commissioned in October, 1916.

On her commissioning trials, the Courageous worked up to full power, and while steaming during the trials at full speed she met very heavy weather. Some signs of weakness were shown at the fore side of the forward turret where there is an inevitable discontinuity of longitudinal strength, and some doubling plates were accordingly added to the Courageous. Her sister vessel Glorious was in commission for over a year before similar additions were made to her, although no signs of weakness were shown. This incident shows that the very high speed obtained on trial, reaching 32 knots, should hardly be maintained against head seas in heavy weather.

The Furious was similar to, but a modification of, the Courageous and Glorious, having about the same length and the same machinery, but the form of midship section was somewhat different, having a more pronounced bulge and a simpler form of main framing and structure of the hull. The armament also was different, each turret, instead of having two 15-in. guns, was arranged to carry one big gun of 18-in. bore, although arrangements were made to substitute pairs of 15-in. guns, if thought desirable later.

The order for this ship was placed with Messrs. Armstrong about two months after that of Courageous, and she was to be finished in the shortest possible time. Early in the spring of 1917, however, the necessity for having fast aeroplane-carriers became very obvious, and it was approved to fit Furious for this purpose. This entailed doing away altogether with the fore turret and making other considerable alterations. A large hangar was built on the forecastle deck, and a flying-off platform 160 ft. long was arranged on the roof of the hangar, which was designed to house about ten machines. Later it was decided to remove the after turret as well, and a flying-on deck 300 ft. long, extending from the funnel aft, was constructed. The secondary armament, which had consisted originally of eleven 5½-in. guns, was retained, with the exception of one gun; the remaining 10 guns being rearranged. Four sets of triple 21-in. torpedo tubes were fitted on the upper deck aft, and one pair each side on the upper deck forward. After these alterations were completed the ship was tried and commissioned in July, 1917, a speed of 31½ knots being obtained with 96,000 shaft horse-power at 330 revolutions.

LIGHT CRUISERS. (Plate XXXVI and Fig. 9, page 484).

Following upon the previous light cruisers of the "Town" classes, the particulars of which have already been published, a very important departure was made in the light-cruiser design in the programme 1912–13, when the "Arethusa" class was designed by Sir Philip Watts. The importance attached to speed was specially brought out in this design, and it was decided to instal very powerful machinery with a shaft horse-power of

NAVAL CONSTRUCTION DURING THE WAR.

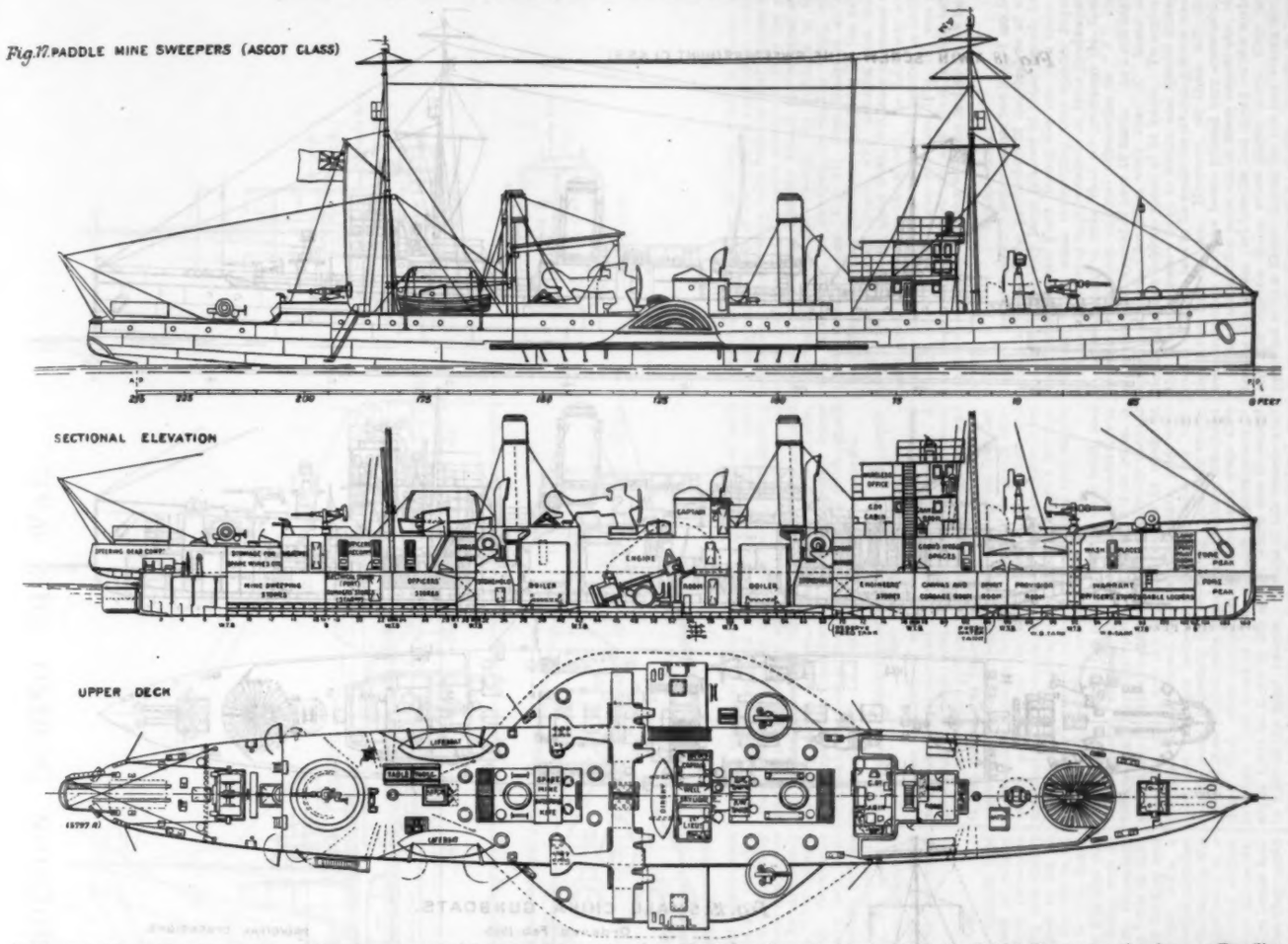


Fig. 17. PADDLE MINE SWEEPERS (ASCOT CLASS)

40,000, and this could only be achieved by adopting a type of engines and boilers closely approximating to those hitherto used for destroyer classes.

In conjunction with high speed a good armament was provided, consisting of two 6-in. and six 4-in. guns, though in the original design the armament consisted entirely of 4 in. The ship's sides up to the level of the upper deck were protected by specially high tensile plating varying from 2 in. to 1½ in. throughout the machinery spaces, in addition to the 1-in. shell plating. This arrangement of plating also greatly added to the strength and stiffness of the ship regarded as a girder. Further particulars of the class are given in the Table on page 483. The Arethusa and other light cruisers were in the action off Heligoland on August 28, 1914, and gave an excellent account of themselves.

In the 1913–14 programme the "Calliope" class, slightly larger vessels than the Arethusa but with the same power, were decided upon. After considerable discussion regarding the merits of mixed or homogeneous armament, it was decided to give these vessels two 6-in. guns, both on the centre line placed aft, and eight 4-in. guns. The protection consisted, as in the previous design, of a 2-in. belt over the shell plating, making a total thickness of approximately 3 in. Most of this class had practically the same machinery as the Arethusa, but Parsons geared turbines were installed in two of them, the Calliope having four shafts and the Champion having only two shafts. This was at the time a very important experiment, the putting of 20,000 h.p. through gearing being a very bold departure from anything which had been hitherto contemplated. The final results obtained with Champion were, however, excellent, and she obtained a speed of 29¼ knots with 337 revolutions and about 41,000 shaft horse-power, this speed being slightly in excess of any of the other vessels of the class at corresponding displacement.

For the subsequent classes I would refer to the Tables, which show a gradual growth in size and power of armament; "Ceres" class (Plate XXXVI) finally having a length of 425 ft. and a beam of 43 ft. 6 in., and a normal displacement of about 4,200 tons. These vessels carried five 6-in. guns, all on the centre line.

The next class were the "D's," the general arrangement and protection of which followed that of the "Ceres," except that six 6-in. guns were carried on the centre line instead of five. The power was only slightly increased in these ships over the previous classes, but the revolutions were reduced to 275, all these later classes having the twin-screw geared arrangement, and although the displacement of the "D's" increased to 4,650 tons, the additional length and the reduction of revolutions enabled the speed of close upon 30 knots of the whole class of light cruisers, "C's" and "D's," to be practically maintained. The "Arethusas" and the "C" and "D" classes all had oil fuel only.

In addition to these light cruisers, which were all to Admiralty design, two vessels—the Birkenhead and Chester—which were built at Messrs. Cammell Laird's for the Greek Government, were purchased in 1915. These vessels were considerably heavier than the "C" class, and more closely resembled the British "Chatham" class. They carried an armament of ten 5¼-in. guns. The machinery was modified to burn oil only, in the Chester, instead of coal and oil as in the Birkenhead, and the resulting increase in power to 31,000 gave the former a speed of 26½ knots.

The "Raleigh" Class.—In the summer of 1915 designs were prepared for a considerably heavier class of light cruisers, more especially designed for ocean work in any part of the world. They were to have a speed of 30 knots and a large radius of action. Various armaments were considered, and it was finally decided to adopt an armament of seven 7·5-in. guns with twelve 3-in. (four being on high-angle mountings). Five of the big guns were placed on the centre line, as shown in Fig. 9, page 484, and the other two were on the broadsides amidships. The bow and stern guns were superposed, thus giving a fire of four guns, both ahead and astern, and six guns on either broadside. The conditions laid down involved a ship of great length, and these vessels consequently have an overall length of 605 ft. These ships were originally designed to burn oil and coal, but this was subsequently altered in three ships of the class to all oil, the original power of 60,000 shaft horse-power on a four-shaft geared turbine arrangement being considerably increased up to about 70,000 shaft horse-power by the change to all-oil firing. These vessels also differed from the light cruisers referred to above in having modified bulges as protection against underwater attack. The form of the section shows how these were arranged. The protective plating was similar to that of the other light cruisers.

MONITORS. (Figs. 10 and 11, page 484.)

The first vessels of this type to be added (or reintroduced) to the British Navy were the three ex-Brazilian river monitors, built by Messrs Vickers, Limited, and taken over by the British Government in August, 1914, and renamed Humber, Mersey and Severn. The particulars of these vessels are given in the Table, page 483. It will be seen that the armament consisted of medium calibre guns, viz., 6-in. and 4·7-in. These vessels, though lightly built, have done very good service in the war, both on the East African and Belgian coasts.

The need for vessels of the monitor type mounting heavy guns soon became apparent, and I received instructions in November, 1914, to prepare designs of monitors of more substantial structure for sea-going service, but of light draught with good protection and carrying some heavy guns, the light draught combining the advantages of being able to go close inshore and of greatly reducing risk of being struck by a torpedo.

The earliest design was that of the 14-in. gun monitors, four in number, which was commenced in 1914. Four twin-mounted 14-in. guns and mountings were available, and with the very simple form of structure adopted, these vessels were designed and built in six months. They were quickly followed by the 12-in. monitors, which were of similar design but carried pairs of 12-in. guns, generally taken from older battleships. These vessels were also built in about six months. They all had a complete bulge of a form which was of simple construction, with an air-space outboard and a water-space between that and the ship proper. This bulge was carried well fore and aft, and the ships being of rather bluff form, the speed was somewhat below that estimated; the bluff form of the bulge having a bad effect upon the propeller performance. However, no particular point had been made about the speed, and we had rather to take what machinery we could get in the shortest possible time.

Following on the 12-in. monitors, early in June, 1915, two more vessels were ordered, mounting a pair of 15-in. guns. For these ships, internal combustion engines, which were well under way, but designed for another purpose, were installed. In September, 1915, two improved 15-in. monitors were ordered and named the Erebus and Terror (Fig. 10). These were of finer form, of more power and greatly increased speed. These vessels also had an improved form of bulge, though it did not differ essentially from the bulges of the earlier monitors. The Erebus and Terror were designed to

NAVAL CONSTRUCTION DURING THE WAR.

Fig. 18. TWIN SCREW MINE SWEEPERS (HUNT CLASS)

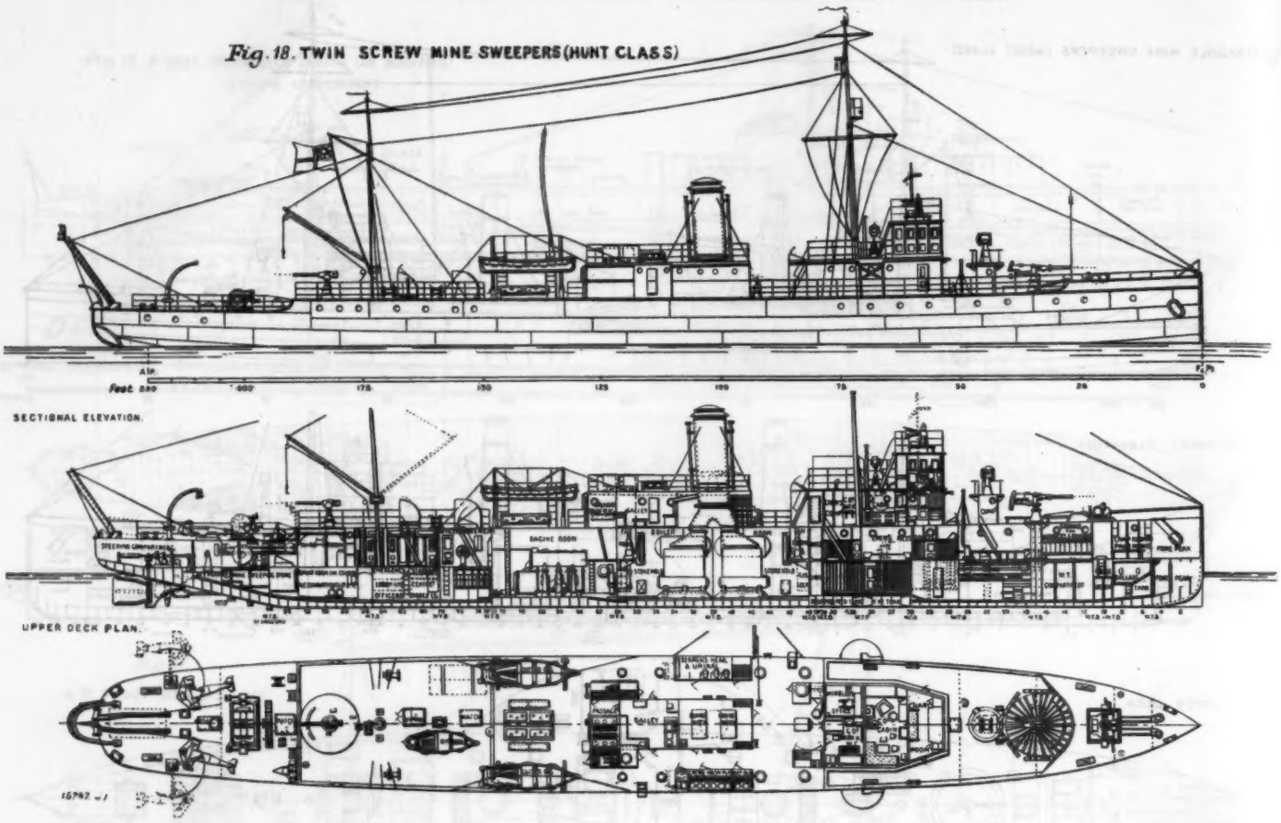


Fig. 19. SMALL CHINA GUNBOATS.

Ordered Feb. 1915.

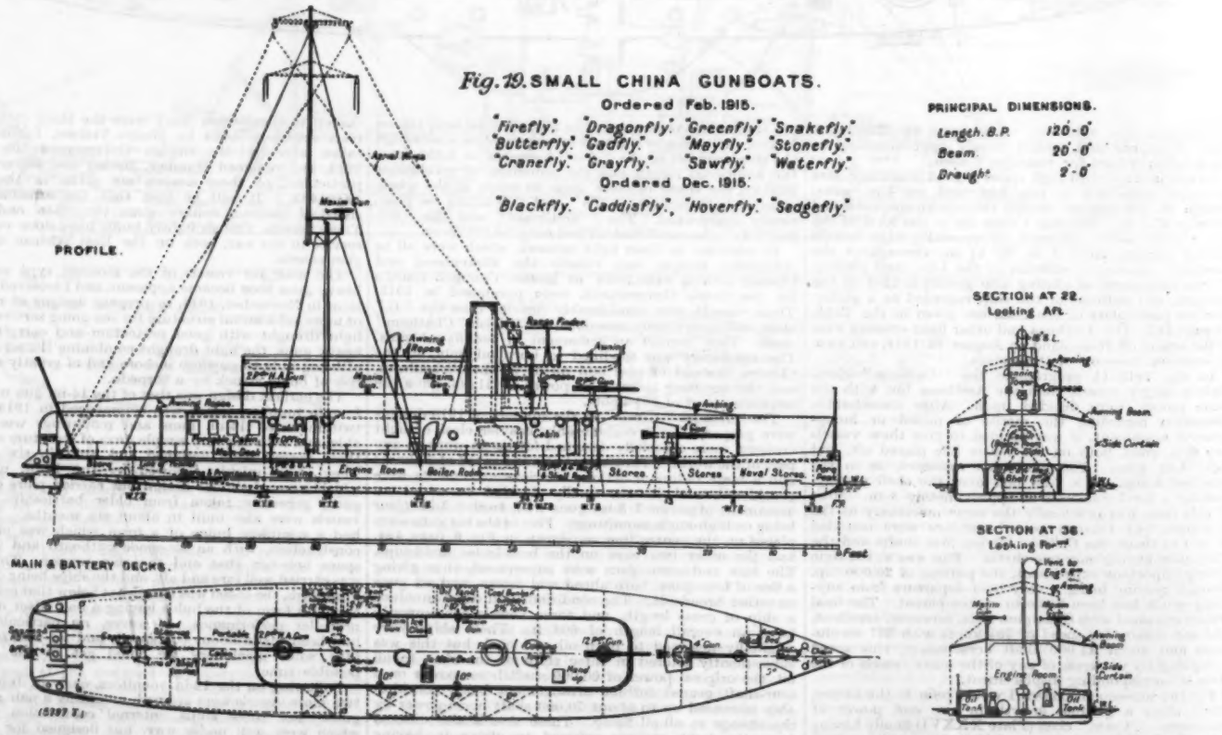
"Firefly." "Dragonfly." "Greenfly." "Snakefly."
"Butterfly." "Gadfly." "Mayfly." "Stonefly."
"Cranefly." "Grayfly." "Sawfly." "Waterfly."

Ordered Dec. 1915.

"Blackfly." "Caddisfly." "Hoverfly." "Sedgefly."

PRINCIPAL DIMENSIONS.

Length, B.P.	120'-0"
Beam	20'-0"
Draught	2'-6"



have a speed of 12 knots when fully laden, but they actually are capable of about 14 knots.

Following the earlier 15 in. monitors, some much smaller vessels, each carrying a 9·2-in. gun, were designed, and others again which carried 6-in. guns (Fig. 11). I need not refer at any length to these, as the general particulars are given in the table. A good many of both large and small monitors went out to the Dardanelles in the early part of the war and did very good work, and for a long time they seemed to bear a charmed life, as they enjoyed complete immunity from torpedo attack. Whether this was due to their shallow draught or to the enemy submarines thinking it was useless to torpedo the bulges, I do not know. Later, however, the Erebus and Terror were both torpedoed: the latter received three torpedoes forward but got to port all right, though severely damaged, two of the torpedoes hitting forward of the bulge; the third, which hit the bulge itself, did very little damage. The former ship was hit full amidships by a distance-controlled boat carrying a very heavy charge, but the bulge gave her complete protection and she was repaired in less than a fortnight. It is interesting to note in this connection also that some of our old cruisers of the "Edgar" class, which had had bulges

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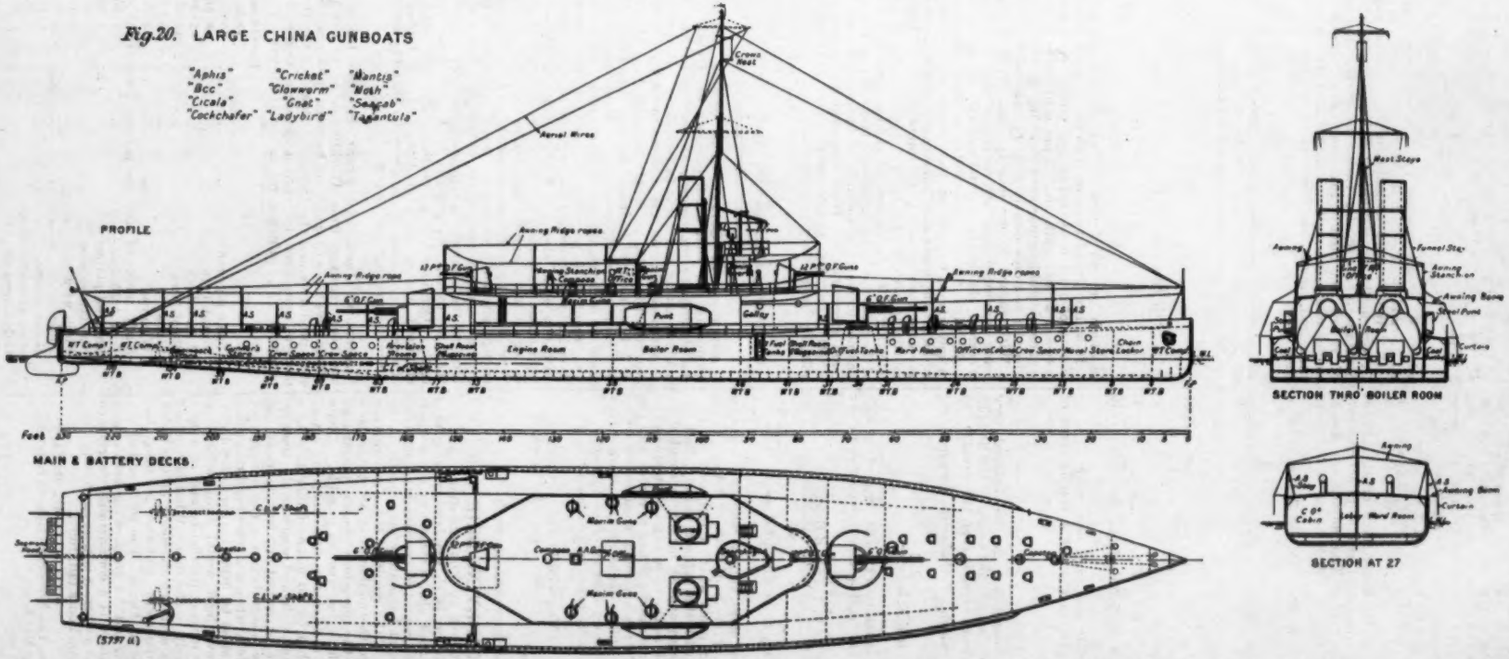
Fig. 20. LARGE CHINA GUNBOATS



added to them very early in the war, were torpedoed in the Mediterranean, but the bulge gave complete protection to the ship proper. They were taken to port and repaired. Of the heavier monitors it may be remarked that of all ships carrying heavy guns these vessels were probably more often in action off the Belgian coast and elsewhere than any of our heavy-gun ships, and they no doubt gave the enemy in occupation of that coast a very anxious time.

Destroyers and Flotilla Leaders.

To give a complete account of the development of the design and construction of our destroyers and flotilla leaders during the war would mean a very long paper, and I think, therefore, I must refer only to the tables and plans (Figs. 12, 13 and 14, page 485) which I give. These vessels have gradually increased in size and power, and war requirements have continually added to the weights which they have had to carry, including considerably more fuel, heavier armament, both of guns and torpedoes, depth charges, larger bridges, and other additions. In fact, some of the ships which before the war were 900-ton vessels, now carry an additional 100 tons, which, of course, is a very heavy handicap to these vessels when expected to maintain a high speed. The introduction, however, of the geared turbine has added enormously to the efficiency of the machinery and propellers; the lower revolutions which can be introduced with the gearing enabling us to adopt much more suitable propellers, in addition to giving a greater economy of fuel.

During the war nearly 300 torpedo boat destroyers and flotilla leaders, which are simply a larger form of torpedo boat destroyer with improved accommodation, have been added to the Fleet, and the whole class of these vessels has been called upon to do continuous work in heavy weather. They have come through the ordeal with extraordinarily few breakdowns of machinery or other parts of the ship, whilst the duties they have been called upon to perform in combating the submarines, convoying, &c., have been most continuous and varied.

Most of the designs have been got out at the Admiralty but certain other, including some torpedo boat destroyers built for foreign countries and taken over by Admiralty have been evolved by the builders, Messrs. Thornycroft, Yarrow, White, Fairfield, Brown, and Hawthorn Leslie. Numbers of these vessels also have been built by firms who had never built a warship before, but the work turned out by them has fully met the Admiralty requirements. The flotilla leaders (Fig. 14), with a deep load displacement of about 2,000 tons and an armament of five 4-in. or 4·7-in. guns, and with their very high speed, might well be described as fast scouts or third-class cruisers.

Patrol Boats. (Fig. 15, page 486).

Patrol boats naturally follow the torpedo-boat destroyers, as they were specially designed to relieve the torpedo-boat destroyers of some of their strenuous duties of patrolling and submarine-hunting and escort work. The conditions were that they had to be as small as possible, consistent with keeping the sea in all weathers. They had to be fast enough to run down submarines, and they had to have shallow draught and all top-hamper kept low to prevent their being seen at a distance. Economy of fuel was also an important feature, and it was desirable to have them built of mild steel rather than high tensile steel, to avoid drilling and special workmanship. They were provided with a special hard steel ram, with which a considerable number of enemy submarines were sunk without damaging the patrol boat. The various features were combined in a vessel of something under 600 tons, with geared turbine engines of 3,800 h.p., giving a speed of over 22 knots, with 330 revolutions of the propellers. The boats had large rudder area and were cut up aft so that they could turn very quickly upon the enemy—a most important feature for ramming purposes. They proved very valuable boats on service and did a great deal of work against the submarines in all weathers. They were armed with only one 4-in. gun, mounted in a commanding position in the forward super-structure, one 2-pounder and two 14-in. torpedo tubes, and later it was arranged to carry depth charges. Their cost was, of course, considerably less than that of a modern destroyer. Some of these boats were afterwards disguised to look like small mercantile craft—a device which proved successful.

Sloops and Mine-Sweepers. (Figs. 16 to 18, pages 486 to 488.

On the outbreak of war it became clear that there would be a great demand for mine-sweeping vessels. A good many coasting and cross-Channel steamers were taken up for this purpose, but more were required, and it was decided in December, 1914, to build 12 single-screw ships of simple design to this end. With the view of hastening construction, it was decided to adopt mercantile practice as far as possible in both hull and machinery. The vessels, although of very fine form, were built of simple construction and under Lloyd's Survey. The boilers were of ordinary Scotch type, and single-screw machinery was provided.

In the end, nearly 100 of these vessels were built, and the armament, which at first was two 12-pounders, was subsequently increased to two 4-in. or two 4·7-in. guns. A great many of these vessels were built in about six months from the order, and the first 36 averaged 24 weeks in building. They proved excellent sea boats, and were used not only for mine-sweeping, but also for submarine work, especially for convoying. At later stages some of these vessels were disguised as ordinary merchant ships. They were economical steamers and were able to attain a full speed of 17 knots, with a horse-power of about 1,800 to 2,000 in the earlier, which was increased to 2,500 in the later, vessels. Several of the vessels were mined, and although the damage they sustained was very severe, they kept afloat and were repaired.

We had the honour of being asked to design and provide some vessels of this type for the French Government, and eight of these were built for that purpose and armed with somewhat heavier armament than our own ships. I understand that the French Government were very satisfied with the vessels. In addition to this, at a later stage, for sweeping in shallow water, some paddle minesweepers (Fig. 17) were designed at the Admiralty, of which particulars are given in the table. These were 15-knot boats, with draught just under 6 ft. 9 in. They did good work, but were of course not such good sea-boats as the sloops. As there was some danger of mines getting under the paddles, a further design of twin-screw mine-sweepers (Fig. 18) was got out, of which particulars are also given in the table. These were vessels of about 800 tons and about 16 knots speed.

Submarines.

As it would make the paper rather too long, I am only giving a table of the particulars of the designs of submarines, but a very large number of these vessels have been added to the Fleet during the war, and some 12 different types, some embodying very special requirements and all being improvements on their predecessors. It is interesting to note that we produced the fastest internal-combustion engined submarine in "J" class, which attained a speed of over 19 knots. As a still higher speed was wanted for Fleet work, the "K" boats were designed with a surface speed of 24 knots. To arrive at this it was necessary to go to steam, and special arrangements of course had to be made for shutting down watertight the funnels, &c. However, all these difficulties were overcome and the boats proved very successful.

It is an interesting point about these vessels also, that besides the steam turbines for full speed on the surface and the electric drive when under water, they were provided with a Diesel engine for use just before diving or immediately after breaking surface, in order to hasten the time of diving or of getting away quickly after coming

up. The transmission from the Diesel engine was through the electric motors, so that these vessels had not only geared turbines for the steam drive, but they also had electric transmission with a Diesel engine and electric battery drive when under water. Although the Germans had the advantage of more power per cylinder in their Diesel engines, we produced faster surface boats, faster underwater boats, and more heavily armed boats than they. M.1 submarine, of which some account and illustrations have already appeared in the Press, was a monitor submarine armed with a 12-in. gun; she was an experimental boat.

"CHINA" GUNBOATS. (Figs. 19 and 20, pages 488 and 489).

I should not omit to mention the two classes of so-called China gunboats, designed by Messrs. Yarrow. The smaller of these vessels (Fig. 19), 120 ft. long and of about 100 tons, were constructed in this country in such a way that the parts could be sent out to Abadan where they were assembled and the vessels re-erected and completed under the supervision of Admiralty officers. Some of the larger boats (Fig. 20), 230 ft. long and of 645 tons, were completed here and went out to Mesopotamia, where all of them were of the greatest service in that campaign. It is impossible to mention all the small craft built, but most useful work was done by motor launches and many other types.

OTHER AUXILIARY CRAFT AND AIRCRAFT CARRIERS.

We were called upon at the Admiralty to design many other auxiliary craft—notably some fast Fleet oilers which were able to carry 5,000 tons of oil and had a speed of 15 knots. We also designed a great number of special smaller craft for all purposes, and we had to take over and modify, sometimes very extensively, a number of merchant ships for various purposes. Probably the most important modifications were those made to vessels taken over and converted into aircraft-carriers, including Campania, Ark Royal, Engadine, Riviera, &c. I have already alluded to the Furious, but one of the "Raleigh" class has also been converted into an aircraft carrier, and is now named Vindictive. The Argus* was originally built as a passenger mail ship of 20 knots and was taken over and converted into an aircraft-carrier with complete flush deck, the funnels being carried aft in long horizontal ducts, discharging the smoke astern. The Eagle, alluded to above, is also being converted into a large aircraft-carrier with a somewhat different arrangement; but it would take too long to go into any detailed account of these ships. There is no question that aircraft-carrying will gradually become more important for the Fleet. Altogether during the four years some 2,000,000 tons have been added to the Navy, at a cost probably between 250,000,000*l.* and 300,000,000*l.* sterling. Reference to the Navy Estimates show that the aggregate sum spent during the four years before the war on new construction amounted to approximately 60,000,000*l.*

AIRSHIPS.

Besides purely ship design and construction, up till the autumn of 1917, as Director of Naval Construction, I was responsible for the rigid airship designs, to which all our existing rigids have been constructed. The responsibility for this branch was in 1917 transferred to a special Airship Production Department, but officers of the Royal Corps of Naval Constructors transferred to the new department continued the work they had been doing on airships.

The above brief account of the design and construction of recent ships will, I hope, give some idea of the extent and scope of the work carried out and the additions made to the Navy during the war, but it really represents the culmination of half a century's effort in developing naval design; and shows, I think, that throughout this period Great Britain had led the way, not only in the personnel but also in the *materiel* of the Navy. In the development of designs the co-operation of other departments of the Admiralty should be fully recognised, especially those of the Engineer-in-Chief and Director of Naval Ordnance, who were consulted throughout as regards machinery, armaments, &c. This is not the occasion for me to dwell on the loyalty and devotion to duty shown by the Royal Corps of Naval Constructors, and all the members of my staff during the strenuous days of the war, but I should like, in conclusion, to say how much assistance we have received throughout from the contractors, who have always given us of their best, co-operating in every possible way, besides lending us some of their best young men, who have done excellent work at the Admiralty. This assistance from the shipbuilders of the country has been absolutely invaluable, and I should like to take this opportunity of thanking all those who have helped us so much in our work at the Admiralty. I cannot conclude without reference to the great advantage derived by interchange of views and consultation with our Allies. Throughout the whole period we have had frequent conferences on matters of design and construction with many allied officers, including those of the French, Italian, Japanese, American, and Russian Navies, certainly to our mutual benefit. Finally, I wish to express my thanks to Mr. C. M. Carter, R.C.N.C., for assistance in compiling the tables given. The plates are reproduced by permission of the Controller of His Majesty's Stationery Office from the "Records of Warship Construction during the War," which have been very ably edited by Mr. R. W. Dana, Secretary of this Institution, while serving on my staff.

COMMERCIAL AVIATION.—To enable firms interested in aviation more easily to carry out their programmes, a certain amount of material, particularly engines, and aeroplanes originally ear-marked for the use of the R.A.F. are to be released. Requests should be addressed to "Secretary, Air Ministry (C.G.C.A.)."

* See pp. 401 and 430 *ante*.

ON SOME PRINCIPLES OF MANUFACTURING INTERCHANGEABLE ARTICLES TO LIMIT GAUGES.

TO THE EDITOR OF ENGINEERING.

SIR,—The article under the above title by Professor Stoney and Mr. Lees in your issue of the 21st ult. (page 361) can be treated in a simple geometrical way which may interest some of your readers.

Using the same symbols as in the article except that E_1 and E_2, the hole and shaft errors, are reckoned positive in the directions corresponding to removing more metal, we have for the probability that the errors E_1 and E_2 occur simultaneously in the region $d\,E_1\,dE_2$:

$$p\,d\,E_1\,d\,E_2 = \frac{h_1\,h_2}{\pi}\,.\,e^{-h_1^2\,E_1^2\,-\,h_2^2\,E_2^2}\,d\,E_1\,d\,E_2 \quad (1)$$

This equation represents the volume of an element taken from a mountain-like solid with elliptical contours parallel to the $E_1\,E_2$ plane. The ellipses are similar and are represented by $h_1^2\,E_1^2 + h_2^2\,E_2^2 = B$, where B is a parameter.

When $h_1 = h_2$ the equation (1) implies a solid of revolution about the origin thus—

$$p\,d\,E_1\,d\,E_2 = \frac{h_1^2}{\pi}\,.\,e^{-h_1^2\,(E_1^2\,+\,E_2^2)}\,d\,E_1\,d\,E_2 \quad . \quad (2)$$

The errors E_1 and E_2 are independent events, but for a given combined error E, they are mathematically dependent, and the locus of all errors E_1 and E_2 whose sum is E, is the straight line

$$E_1 + E_2 = E \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and this straight line is distant from the origin only $E/\sqrt{2}$.

Thus it is clear that the combined error $E_1 + E_2$ has a probability equal to that of a simple error of amount $\frac{E_1 + E_2}{\sqrt{2}}$

The new accuracy coefficient can be deduced very simply by taking new axes at right angles to the line (3). The locus of the combined error is then the straight line $E_1 = \frac{E}{\sqrt{2}}$ and the width of the strip corresponding to a range of E equal to $d\,E$, is $\frac{d\,E}{\sqrt{2}}$

Thus integrating equation (2) with regard to dE_2 between the limits $-\infty$ and $+\infty$ we have remaining:

$$p\,.\,d\,E = \frac{h_1}{\sqrt{\pi}}\,e^{-h_1^2\left(\frac{E}{\sqrt{2}}\right)^2}\,\frac{d\,E}{\sqrt{2}}$$

which gives the accuracy of the combined error $= h = \frac{h_1}{\sqrt{2}}$

This method shows more vividly why the accuracy of fit is 0·707 of the accuracy of shaft or hole.

There is one other point which I feel deserves emphasis in connection with this subject, namely, that the caution of the workman against making a small shaft or a large hole, as well as the allowances for wear by the tool maker, cannot be classed as random errors, and the resulting accuracy of fit is not really accuracy of workmanship in the probability sense of the word. If a rifleman aims at the heart instead of at the centre of the body, he will probably cause more deaths but fewer wounds.

Yours faithfully,
H. S. ROWELL.

Elswick, April 2, 1919.

H.M. SEAPLANE-CARRYING SHIP "ARGUS."

TO THE EDITOR OF ENGINEERING.

SIR,—In the article on H.M. seaplane-carrying ship Argus, published on 28th ult., a statement which needs correction is made with regard to experiments conducted at the National Physical Laboratory on a model of the ship. It is said that "the result of these experiments showed that to ensure the minimum of air disturbance it was necessary that the space between the hangar roof and flying deck should be as open as possible." Even supposing this to be a necessary condition, the actual construction of the ship by no means fulfils it. As a matter of fact, the tests showed conclusively that no useful purpose would be served by leaving clear the comparatively narrow space between the hangar roof and flying deck, especially when it is considered that some supporting structure must be fitted between the decks. Such a structure, however light, would always effectively close the space to air moving parallel to and at a considerable speed relatively to the ship. What is required is that there shall be as much overhang of the flying deck as possible at the stern, and this condition has been well provided for in Argus. The stern end of the deck is carried well aft, and the width of the deck is well maintained, so that there is a considerable clear space beneath, just at the place where it is most essential.

Yours faithfully,
L. W. BRYANT.

Aerodynamics Division, The National Physical Laboratory, Teddington, Middlesex.
April 3, 1919.

CIVIL AERIAL TRANSPORT.

TO THE EDITOR OF ENGINEERING.

SIR,—As Mr. Zaiman's letter seems to have failed to convince Mr. Wolff of the error of his ways, I feel constrained to show in detail where the false assumption which he seeks so blindly is to be found. His work begins by quoting a result of Sir G. Greenhill's

$$\text{H.P.} = \frac{2\,K}{330}\cdot\frac{W^2}{A}\cdot\left(\frac{12}{K}\right)^2$$

This result was attained, as I pointed out, by assuming weight, attitude, altitude and speed constant during the whole flight. Under these impossible conditions, for minimum petrol consumption it was found that

$$A = n^2\,B$$

Therefore, for a particular aeroplane of given A and B, the value of n is fixed.

Now

$$W = \frac{A}{n}\left(\frac{K}{12}\right)^2$$

where W is the original weight; we have, therefore, A, n, K all constant, but yet W is diminishing!

Mr. Wolff's false assumption is, therefore, that Sir G. Greenhill's expression for H.P. which holds for W constant is correct for variations of W. For change of W we can discuss two conditions of flight which render analysis comparatively simple; either the altitude and, therefore, the relative air density change such that

$$w = \sigma\,W$$

where W is the weight at any time when the relative air density is σ; or the altitude remains constant, and the speed K changes, so that at any time

$$w = \frac{A}{n}\left(\frac{K}{12}\right)^2$$

In both cases Mr. Wolff will find that

$$\text{H.P.} = \frac{2\,K}{330}\cdot\frac{W}{n}$$

to which form Sir G. Greenhill's result also reduces.

It will be found that for the case $P = \frac{1}{4}W$, the range instead of being increased 50 per cent., is only increased between 21 per cent. and 22 per cent. This difference is of considerable importance on a long flight, and explains why the accuracy can only be "accidental."

With regard to air density, Mr. Wolff, apparently being convinced that my reading of Air Board figures is correct, changes his ground and attacks me for finding fault with Sir G. Greenhill's original statement. I merely wished to point out that in this, as in other places in the article, there were important mistakes in detail. In any case, even speaking in "round numbers," hardly reconcilable with Mr. Zaiman's "speaking roughly without referring to actual figures"—when a range of a quarter of the greater number is given, it is surely a pity the range was not increased sufficiently to include the true value! I am sorry that Mr. Wolff has been laid up for fifteen months, but Mr. Dine's figures were in general use, officially, more than two years ago.

Yours faithfully,
O. GLAUERT.

9, Waverley-road, Norwich, April 1, 1919.

ANTIMONY IN COPPER.—The opinion has gained ground of late that small percentages of antimony do not deteriorate the copper, as used to be feared, but made it harder and left it fit for rolling. Reviewing the recent researches on the problem in *Metall und Erz*, of November 8, 1918, W. Stahl concludes that 0·3 per cent. or 0·4 per cent. of antimony are not at all objectionable, if present as metal or as copper antimoniate. A total impurity of the same amount of both nickel and antimony, *i.e.*, about 0·15 per cent. of each of these metals, is likewise to be welcomed rather than to be deprecated; such copper is also sound when hot. Combined with high nickel percentages, however, even a little antimony is bad; what is said for nickel, also holds for manganese. When the copper contains bismuth, up to 0·05 per cent., enough antimony should be added to the fused copper at the commencement of the oxidation period to transform all the bismuth into antimoniate; the copper may then be rolled. As regards lead, similar restrictions apply. Considerable proportions of both lead and antimony are certainly injurious; a few thousandths of a per cent. of lead can, however, be bound by antimony without impairing the copper.

AMERICAN IRON AND STEEL PRICES.—Information has been received from Washington as to the prices which have been agreed upon between the United States steel producers and the Industrial Board of the Department of Commerce, for various classes of iron and steel products. The principal prices are as follows:—

	Per Gross Ton. Dols.
Basic pig-iron	25·75
4-in. billets	38·50
2-in. billets	42·00
Sheet bars	42·00
Slabs	41·00
Wire rod	52·00
Skelp, grooved (merchants have base of 2·35 dols.)	Per Cwt. 2·45
Sheared plates	2·65
Structural base	2·45
Plain wire	3·00
Nails	3·25
Black sheets	4·35
Blue annealed sheets	3·55
Galvanised sheets	5·70
Hoops	3·05
Light rails	2·45
	Per Gross Ton.
Rails (standard Bessemer)	45·00
Rails (standard O.H.)	47·00
	Per Base Box.
Tin plates	7·00